

# COMPUTER PROGRAMMING FOR COOLING TOWER PERFORMANCE

by

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DEPARTMENT OF MECHANICAL ENGINEERING  
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FOR  
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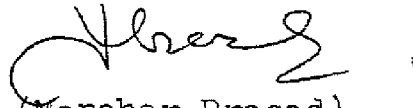
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CERTIFICATE

This is to certify that the thesis entitled,  
" Computer Programming for Cooling Tower Performance"  
by Mr. K.A. Nagabushana is a record work carried out  
under my supervision and the same has not been submitted  
elsewhere for a degree.

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# NOMENCLATURE

A	- Tower reference plan area
BLD	- % Blowdown of water/hr
CFIL	- Cost of wood/m <sup>3</sup>
COP	- Cost of power/KW-hr
CWAT	- Cost of water/m <sup>3</sup>
CWOOD	- Total cost of wood
C1,C2,C3,C4	- Constants depending upon the type of fill arrangement
D	- Diameter of water droplet in mm
d	- Diameter in m
GE	- Equivalent mass of air
g	- Acceleration due to gravity in m/sec <sup>2</sup>
HEAD	- Total pumping head
HR	- Number of hours/year
h	- Enthalpy in kcal/kg of dry air
k	- Thermal conductivity in kcal/m-hr-°C
Le	- Lewis number $h_c / (h_D c_{pa})$
LKG	- % leakage of water/hr
M	- Number of elements in i direction
m	- Mass flow in tower - kg/hr
N	- Number of elements in j direction
n	- Number of decks
OF	Tower operating factor

P	Pressure in $\text{N/m}^2$
VOLSEC	Volume of air blown/sec
POWFAN	- Power for fan in KW-hr
PPOW	- Power for pump in KW-hr
Pr	- Prandtl number
PUMCOS	- Cost of pumping
Re	- Reynolds number
T	- Temperature in $^{\circ}\text{C}$
TOTWAT	- Total water required/year
V	- Total volume of tower in $\text{m}^3$
VOLF	- Volume of fill in $\text{m}^3$
VSEC	- Face velocity in m/sec
W	- Humidity in kg of water/kg of dry air
WATCOS	- Cost of water/ $\text{m}^3$
X	- Mol-fraction of air in moles dry air/ moles moist air
X	- Number of Years
$A_v$	- Surface area of water droplet in $\text{m}^2/\text{m}^3$
$C_o$	- Total cost over projected life
$C_p$	- Specific heat in $\text{kJ}/^{\circ}\text{C}$ -kg of dry air
$C_t$	- Total cost of tower for the projected life
$t_r$	- Pipe frictional co-efficient
$q_c$	- Universal gravitational constant
$h_c$	- Heat transfer coefficient in $\text{kcal/hr-m}^2\text{-}^{\circ}\text{C}$
$h_D$	- Mass transfer co-efficient in kg of dry air/hr $\text{m}^2$

$K_e$	Combined heat and mass transfer coefficient
$r_{Int}$	- Rate of discount
$V_r$	- Relative velocity of air
$Z_f$	- Distance between each deck in m.
$\Delta P$	- Pressure drop in mm of water
$\Delta V$	- Elemental volume of tower in $m^3$
$\rho$	- Density in $kg/m^3$
$\nu$	- Kinematic viscosity in stokes
$\mu$	- Absolute viscosity in $kg/m\text{-sec}$

#### SUFFIX

a	- air
av	- average value
db	- dry bulb
e	- equivalent
ev	- evaporation
f	- saturated liquid state
fg	- evaporated state
g	- saturated vapour state
i	- number of row
j	- number of column
pip	- pipe
re	- rate of evaporation
s	- saturated condition
wb	wet bulb

## ABSTRACT

The governing equations for a cross and counter-flow cooling towers are derived using heat and mass transfer considerations. The finite element method was used to solve these equations for various ranges of parameters. The optimum number of fills were determined for a desired exit water temperature using iterative scheme.

In case of a given exit condition of water the NTU and tower characteristics were also determined using variable as well as fixed mass of water. When the evaporation of water was considered, it was found that the tower capacity gets increased by about 6 to 7%.

The effects of Lewis number shows significant effect on the exit conditions based on recommended Lewis numbers. Hence the present method considering the variable/average Lewis number should be used for the evaluation of the tower characteristics.

Finally, cost analysis has been carried out for constraints like water load, fills, etc., considering over a period of the tower life. It has been found that the make up water dominates over costs of power, machinery and packing material.

## INTRODUCTION

1.1 Need for Cooling Towers [4, 13, 14, 19, 30]

The disposal of waste heat is a most common feature in power plants, refrigeration systems and industries. In many processes it is even necessary to dispose of heat from certain part of the plant

1. in order to get rid of the local temperature gradient
2. the vast quantity of heat generated cannot be put to good use for various reasons.

At the same time with the industrial progress the need for cooling equipment with sophisticated designs have grown up for the process of heat removal. Water and air are readily and naturally available in abundance as cheapest agencies. Owing to gaseous nature, greater quantities of air is required to perform the same function as water. Thus water is generally chosen as a cooling media.

In thermal power plants each MW of power generation demands 2 MW of heat rejection. Similarly, in vapour

compression refrigeration systems each ton of cooling requires about 1.3 ton of heat rejection. If air is used to reject 2 MW of heat with about  $10^{\circ}\text{C}$  of temperature rise, one needs 2000 kg/s of air as compared to only 500 kg/s of water. In olden days, due to this large requirement of water and lack of knowledge of cooling towers, the industries were situated at the water resources, like - lakes, large ponds, canals, river etc. The abundant water resources made it possible to use cold water on once through basis. However, the number of rivers and lake sites are limited, and the average temperature of such water frequently rises owing to growing number of plants. Also in many countries in the light of ecological renaissance it is environmentally unacceptable to discharge hot water directly to source after its use for cooling. The hot process water must be either cooled before discharge or cooled and recycled. Purchasing and then discharging large quantities of water into sewage systems is cost prohibitive. Even if favourable economically, such practice is socially restricted and environmentally prohibitive. Moreover the site selection for an industry may prove to be profitable to locate it where water is scarce. It implies therefore to develop a system which can cool the warm water with least use of make up water. This has led to the development of evaporative cooling device-Cooling Tower.

## 1.2 Historical Background and Development in Cooling Towers 6, 14, 16, 18, 19]

In spite of present widespread and continually growing use of cooling towers for heat dissipation in various industries comparably less information was available in the past. The development, as a whole or in part, took place within last century. Water has always been the most convenient medium for removing the heat, and recooling became necessary as the required quantity of cooling water increased.

Cooling towers function on the principle of evaporative cooling. Although the art of evaporative cooling is quite ancient, it has been studied scientifically very recently. The first use of evaporative cooling dates back to 2500 B.C., where the porous jars were used to get cool water. In persian countries it was customarily to cover their tents with wet felt in order to find shelter from oppressive heat. And the permanent houses were built half underground and running water was flown into a small indoor pool. The same principle of evaporative cooling was made use of in making ice in olden days.

After continual development it was discovered that by spraying downwards in a box, instead of upwards,



instead of relying on prevailing winds for air movement in spray ponds and atmospheric spray towers, aerodynamically designed fans were incorporated into the system. The betterment in system was brought about by fill or packing material to increase the retention time of water and provide greater air/water interfacial contact for more efficient cooling.

Cooling tower technology appears to have made an entire circle, as emphasis is again directed towards atmospheric cooling. However, there are significant differences in these modern designs compared to early prototype. The hyperbolic cooling towers are being constructed, now-a-days, without the use of fans or air movers.

### 1.3 Literature Survey [5, 6, 14]

The first technical consideration of the problem was given by Robinson C.S., in 1922. It was further developed by Walker, Lewis and McAdams in the following years. They developed the basic governing equations for Heat and Mass transfer as two different processes in the tower design, and developed an interesting relationship between Heat and Mass transfer co-efficients, but did not use. Later Lewis W.K., found the same relationship and was named after him as "LEWIS'S LAW",

$$Le = f \text{ (Conductivity/Diffusivity)}$$

$$= h_c / (h_d * c_{pa})$$

During the same year it was noted by Nusselt W., and was verified by Schmidt E. In the case of water evaporating into air, conductivity is approximately equal to diffusivity, so that their ratio is unity. Montgomery R.B., finds it equal to 0.84 and Hansen H., puts it at 0.94.

The generally accepted concept of cooling tower performance was developed by Merkel F., in 1925. A number of assumptions were used to simplify the development of final governing equation for the process. They can be listed as

1. There is no reduction in the mass flow rate of water due to evaporation,
2. Enthalpy of a saturated mixture of air and water vapour is a measure of the enthalpy of any mixture having an equal wet bulb temperature,
3. Lewis number is a constant,
4. Each particle of water is surrounded by a film of air that is saturated with moisture at the temperature of the water.

Accuracy was sacrificed as a result, but modifications may be made in the direct application to minimize the resulting error. Merkel F., for the first time, utilized the Lewis relationship to combine the coefficients of sensible heat and mass transfer into a single overall heat transfer co-efficient based on enthalpy potential difference as the driving force in the cooling tower. The governing equations were developed considering Heat and Mass transfer process taking place together.

In 1939, Colburn A.P., made an attempt in determining tower characteristics. In 1943, Lichtenstein J., handled the basic equations in a slightly different manner, and also produced a method of plotting the Number of Transfer Units and Tower Characteristics to facilitate the tower selection. At the same time, Hutchison W.K., and Spirey E., established a non-dimensional treatment for cooling towers problems.

Mickley H.S., in 1949, developed a more rigorous analysis considering temperature and humidity gradients, heat and mass transfer coefficients from water to film, and from film to air. Eventhough the process involved in a cooling tower is necessarily complex, the analysis offered by Mickley provides offers a possible means of evaluating the given cooling tower. The difficulty lies in obtaining the test data necessary to evaluate them.

During the same years Colburn A.P., and King W.J., showed that the effect of the hot water temperature is a function of the deck geometry and spacing. At first they found a conventional way of representing heat transfer for the tower in the form of plot against the air pressure drop which occurs during the process. They found that for a given air rate and tube diameter, the relationship was nearly linear. Kays W.M., and London A.L., made tests on finned tubes and correlated relative heat transfer with a friction-power constant. More recently Kelly N.B., and Swenson L.K., were able to evaluate empirical equations relating to tower performance with air pressure drop.

In 1950, Wood B., and Betts P., outlined a mathematical and graphical synthesis for natural draught towers, leading Chilton H., to determine some generalised simplifications in ascertaining the performance of such towers. Chilton examined the natural draught towers in detail for values of  $m_a/m_w$  varying from 0.5 to 1.5 for particular approaches and wet bulb temperatures, and showed that under usual operating conditions, Merkel's approximate solution will give a result close to results obtained by accurate integration with cooling ranges of 5°C to 10°C. In 1955, Margen P.H., established some very ingenious relationships between friction and heat transfer applicable to both Mechanical

and Natural draught water cooling towers. At the same time work was carried out comparatively independently along other lines, mainly with a view to obtain more efficient packings and more suitable heat transmission devices by Koch W., Mulder T.J.C., Otte W., and Velut J.

In 1950, a Cooling Tower Institute was established which is a non-profit, self-governing technical association dedicated to improvement in technology, design, performance and maintenance of cooling towers. Prevention of water and air pollution are the prime concern of the institute.

#### 1.4 Technical Aspects in Cooling Tower Design [12, 15, 16, 29, 32]

Design of a cooling tower is quite complex . It is developed through a series of steps that consider the inter-relationship of many components and parameters like:

1. Selection of a proper cooling tower size,
2. The calculation of a required air flow rate,
3. Static pressure imposed by the tower,
4. External environmental factors which affect the air entering the tower,
5. Variation in requirement of the industry,
6. Optimum cooling tower design conditions.

It requires many tables, charts and correlations based on analytical as well as experimental data to predict the design quantities. Unfortunately, there is no single, simple meter, gauge or other mechanical device available to measure the capacity of a cooling tower. Testing a cooling tower can be a relatively simple task, but since it is seldom possible to test a tower at the design condition. The purchaser wants all the equipments that comprise plant investment completely with specific standards and capacity.

Owners, and their system designers, quite naturally want a cooling tower to perform a specific duty as predicted. Therefore, a systematic analysis of imposed heat load; the preferred water flow rate; the required cold water temperature; and a design wet bulb temperature etc., are essential. Similarly, manufacturers want full-rated performance from the cooling tower designers in order to compete with the market.

Design conditions are specified for the particular requirements before a cooling tower is purchased in order to get rid of inadequacy of the cool water temperature or volume. During operation all the cooling towers are expected to function at 100% of their capacity at the designed conditions. In actual

usage, the same may not be true due to

1. Slippage due to usage and defective maintenance might have reduced the performance efficiency of the tower over years of operation.
2. The installation would have been originally undersized or the present service being greater than the original requirements for which the tower was purchased.
3. New plant may need additional water and possibly colder temperature.

Thus a thorough study of a cooling tower becomes necessary, especially in large industrial installations such as electric power plants, nuclear stations, chemical plants, steam generating plants, oil refineries, refrigeration etc. in which cooling tower size and performance are closely integrated with the size and cost of other system equipments.

### 1.5. Present Work [25]

The present analysis follows a finite element technique for solution of governing equations using mass and heat transfer. The computations are carried out for the following cases:-

1. Exit state of water for the given cooling tower characteristic,

2. for a given tower volume
3. the determination of tower characteristics.

The study has been mainly concentrated on cross-flow tower with partial attention to counter-flow towers.

In the analysis of cross-flow cooling towers finite element technique [8] is made use of. The governing differential equations [10] used in this analysis are derived considering heat and mass transfer together, with the tower volume as the control volume. An iterative scheme is developed in predicting the required outlet conditions of cold water with variable parameters.

Before starting an iterative scheme with the help of DEC-10 computer system, computations were carried out to find the permissible number of rows and columns, to save the computation time which is quite valuable.

The computer program [4, 9, 20, 22, 25, 27, 31] is made as general as possible with a wider flexibility in selecting range, approach, volume of tower, type of fill used, water loading and face velocity of air. Studies are made covering all the practical range of each parameter. For a required outlet condition the minimum size of tower, number of fills, velocity of air etc., were computed for a set of inlet conditions. Later the program was extended to findout whether the selected size is quite



ufficient or not. To start with a set of dimensions are selected for the tower and the volume required for the given inlet and required outlet conditions, is calculated based on the mass of water evaporated on the enthalpy separately. Finally comparison is made about the selection of dimensions.

Comparative performance and pressure drop characteristics have been carried out. For this purpose the dimensionless numbers known as "Number of Transfer Units" and "Tower Characteristics" were determined and studied for the specific tower under consideration.

Finally economical aspects [28] are dealt with. As the data availability ~~were~~ extremely difficult a flexible program has been developed. Some results have been found for the available data.

THEORY OF COOLING TOWERS2.1 Operating Principles [13, 14, 19]

Cooling tower operation is mainly based on evaporative consideration and exchange of sensible heat. The mixing of two fluid streams at different temperature releases enthalpy of vaporization, causing a cooling effect to the warmer fluid. Thousands of years ago water, on this principle, was cooled in the porous earthen pots and now-a-days in canvas water bags.

In evaporative cooling three processes take place simultaneously,

1. transfer of heat by convection of sensible heat from warm water to cooler air,
2. due to mass transfer in the form of water molecules, because the main body of the air is at a lower vapour pressure than that of the water surface,
3. due to transfer of heat from the bulk of the liquid to the surface.

Among these three processes, effect of third process is negligible, since the thermal resistance to such direct internal conduction is very less. The evaporation on the convex surface of a drop is so intense that it can take place even in an atmosphere damp enough for condensation to occur on nearby objects. On the other hand, the vapour resulting from evaporation of the water has a low specific weight and contributes to the draught. This effect is known as "Thomson effect" [14].

In a cooling tower operation, sensible heat also plays an important role. Sensible heat, defined as heat that changes temperature, is also part of the cooling process, because when water is warmer than air in addition to evaporation air cools the water and its temperature rises as it gains the sensible heat of the water. Thus transfer of sensible heat from water to air takes place. On an average 75% of total heat is removed by evaporation and 25% by sensible heat transfer. In simple terms, a cooling tower is a simple air-mass heat exchanger that transfers heat from one mass to another.

## 2.2 Cooling Tower Terminology [1, 13, 14, 19, 32]

**2.2.1 Ambient Wet-Bulb Temperature ( $T_2$ ):** Temperature to which air can be cooled, making it adiabatic to saturation by the addition of water vapour.

2.2.2 Approach ( $DESTAV - T_2$ ) It is the difference between the outlet water temperature from the tower and the ambient air wet-bulb temperature.

2.2.3 Blow Down: The continuous (Fig. 2.1.a) or intermittent (Fig. 2.1.b) removal of a part of water from basin in order to maintain concentration of salt and other impurities as described below

$$\text{Blow Down} = 100 \times \left( \frac{\text{permitted chlorides in the make up water}}{\text{permitted chlorides in the circulating water}} \right)$$

2.2.4 Capacity: The average amount of water circulating in the cooling system per unit time.

2.2.5 Cooling Factor ( $m_w/m_a$ ): It is the ratio of mass of water entering the tower per unit time to the amount of dry air per unit time passing through the tower.

2.2.6 Cooling Range ( $T_3 - DESTAV$ ): It is the temperature difference between the inlet hot water to tower and outlet water from tower. The maximum attainable cooling range in cooling tower is temperature difference between the inlet hot water to tower and wet-bulb temperature of ambient air ( $T_3 - T_2$ ).

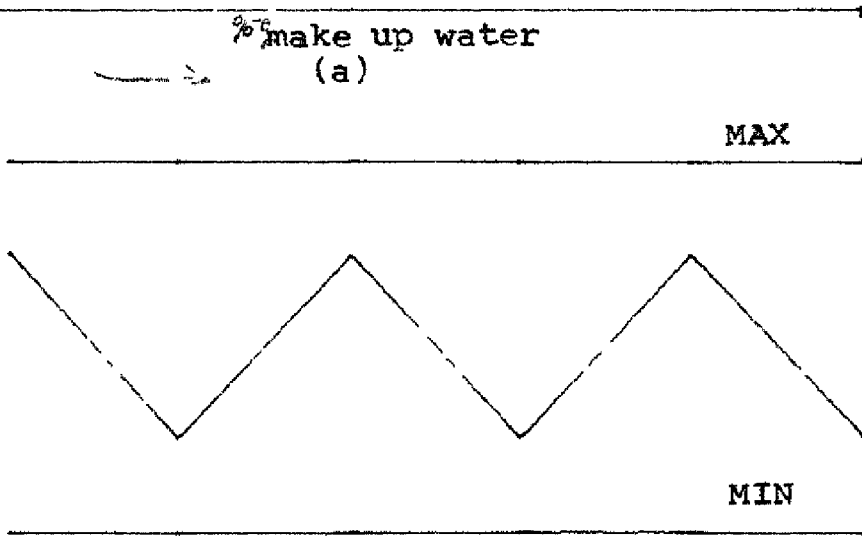
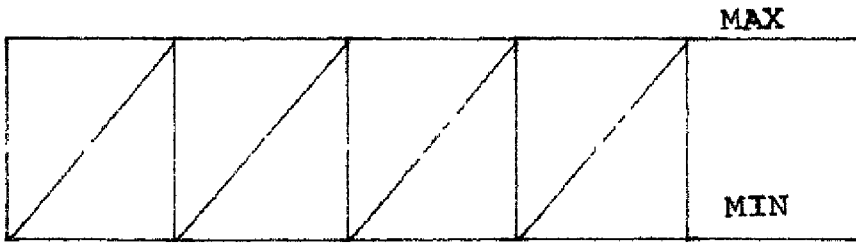


Fig 2.1.a Intermittent blow down  
 2.1.b Continuous blow down

- 2.2.7 Counter-Flow A system in which one fluid flows opposite to the other (i.e., their flow velocities are  $180^\circ$  apart). In cooling tower air comes into contact with hot water at  $180^\circ$  angle, air enters near the base of the tower and moves upward through the fill and falling water.
- 2.2.8 Cross-Flow: A system in which one fluid flows at  $90^\circ$  to the other flowing fluid. In cooling tower the air enters through the entire side wall and moves horizontally through the fill and falling water.
- 2.2.9 Cycles of Concentration: It compares dissolved solids in make up with solids in the circulating water. Since chlorides are soluble, cycles of concentration is equal to ratio of chlorides in circulating water to chlorides in make up and can be expressed as reciprocal of 'Blow Down'.
- 2.2.10 Drift Eliminator: Baffling arrangement provided after the tower fills with a view to eliminate out going hot air associated with water droplets to change direction few times. Droplets hit the eliminator surface and fall back into the tower.

- 2.2.11 **Drift, Windage or-Carryover Loss** The amount of water that is carried away from cooling tower by air in the form of mist in the process of cooling. It is expressed as % of water circulated.
- 2.2.12 **Evaporation Rate:** The rate at which water is being evaporated to cool the circulating water. The heat of evaporation is furnished by the cooling of the circulating water.
- 2.2.13 **Fill Packing.** Specially designed baffling used to provide a large contact surface between hot water and air.
- 2.2.14 **Fog:** A mist formed where the ambient air cannot absorb all the plumes moisture.
- 2.2.15 **Forced Draught:** Air introduced at the bottom of the tower is forced to the top by blower (usually centrifugal or radial).
- 2.2.16 **Heat Load:** The amount of heat (kJ/s) dissipated in a cooling tower expressed as product of water load and range i.e.,
- $$\text{Heat load} = m_w * c_{p_w} * (T_3 - \text{DESTAV})$$
- 2.2.17 **Induced Draught:** Air mover, usually an axial fan, on top of tower sucks air through the fill and discharges it out of the tower.

- 2.2.18 Louvers Baffles used for changing the direction of air flow through a tower in a uniform, parallel manner and preventing water droplets from splashing out of tower as they fall through the structure.
- 2.2.19 Make Up Water: The amount of water required to replace normal system losses caused by evaporation, drift, blowdown and small leakages.
- 2.2.20 Plume: Visible manifestation of water vapour leaving the tower.
- 2.2.21 Retention Time: The time required for water to fall from the distribution header to the cooling tower basin.
- 2.2.22 Water Load ( $\dot{m}_w$ ): Water circulation rate over the tower expressed in terms of mass per unit time.

### 2.3 Classification of Cooling Towers [1, 2, 13, 19, 21, 30]

Most cooling towers perform the same function as an automobile radiator, transfer heat from warm circulating water to atmosphere. However, in the former the hot water and ambient air comes in direct contact during the course of heat transfer. As such they are known as WET TOWERS. They can be classified as follows



1. Based on method of air introduction to the tower or type of flow,
  - i. cross flow
  - ii. counter flow
  - iii. cocurrent flow
2. Method of heat dissipation-
  - i. wet cooling
  - ii. dry cooling
  - iii. wet-dry cooling
3. Based on application,
  - i. industrial
  - ii. power plant

The principal type of towers under first classification can be written as:

- |                     |                         |
|---------------------|-------------------------|
| 1. Ponds            | i. natural cooling pond |
|                     | ii. spray cooling pond  |
| 2. Natural draft    | i. spray filled         |
|                     | ii. splash filled       |
|                     | iii. hyperbolic towers  |
| 3. Mechanical draft | i. forced draft         |
|                     | ii. induced draft       |

The various types of towers can be compared in term of flow area occupied for the same amount of heat removal and is as shown in Table 2.1.

TABLE 2.1COMPARISON OF THE TOWERS FLOOR AREA'S FOR THE SAME HEAT LOAD

TYPE OF TOWER	RELATIVE FLOOR AREA OCCUPIED
NATURAL COOLING POND	1000
SPRAY POND	50
SPRAY FILLED ATMOSPHERIC TOWER	15
SPLASH FILLED ATMOSPHERIC TOWER	4
MECHANICAL DRAFT COUNTER FLOW TOWER	1.5
MECHANICAL DRAFT CROSS FLOW TOWER	1.2 to 2

### 2.3.1.a Natural Cooling Pond:

Both artificial and natural water reservoirs are used as cooling ponds. The warm process water is introduced at one end and a cooled water is withdrawn from the opposite end, in order to avoid short circuiting of warm water. To achieve best results, the total area of the water surface should be as large as possible. Two or more ponds can be used together to transfer a large quantity of heat. To increase the heat dissipation the ponds are constructed below earth surface.

Advantages:

1. Less initial investment cost,
2. Low maintenance cost,
3. Longer life,
4. Doesnot require make-up water for a long period.

Disadvantages:

1. Its heat removal capacity is very low ( $70 \text{ kJ/m}^2$  of surface area-hr-°C)
2. Special attention is required in order to prevent detritus entering the pond and growth of water vegetation,
3. Larger surface area for the ponds cause serious problem in industrial cities,

4. Effect of solar radiation during summer affects the upper water layer and its temperature will be higher than the temperature of water at certain depth, leading to serious problem in selecting position of cooled water outlet.

#### 2.3.1.b Spray Pond:

It differs from the natural cooling ponds because the hot water is carried to a height of 2-3 meters over the basin and sprayed through a spray system consisting of a network of distribution pipes fitted with spray nozzles. In some cases the distribution nozzles sprays water vertically from the surface of the water in the pond. Water cools as air mixes with the spray and evaporates some of it. Air movement depends on atmospheric conditions and the aspiring effects of the spray nozzles. These types of ponds are built at a site which is open to wind from all directions. They are usually situated at a distance from buildings and roads to avoid nuisance to inhabitants because of the formation of fog.

Disadvantages: 1. Performance is limited by relatively short contact time of air and water spray,

2. In absence of louvers and fine spray more drift losses occur calling for more make-up water,
3. Height of spray is limited due to pump energy requirement,
4. Collection of dust and impurities due to the open surface to atmosphere leads to more maintenance cost,
5. Causes considerable environmental nuisance,
6. Although spray tanks are more compact in design and better in their performance than natural ponds, they still require larger area and have limited performance capacity.

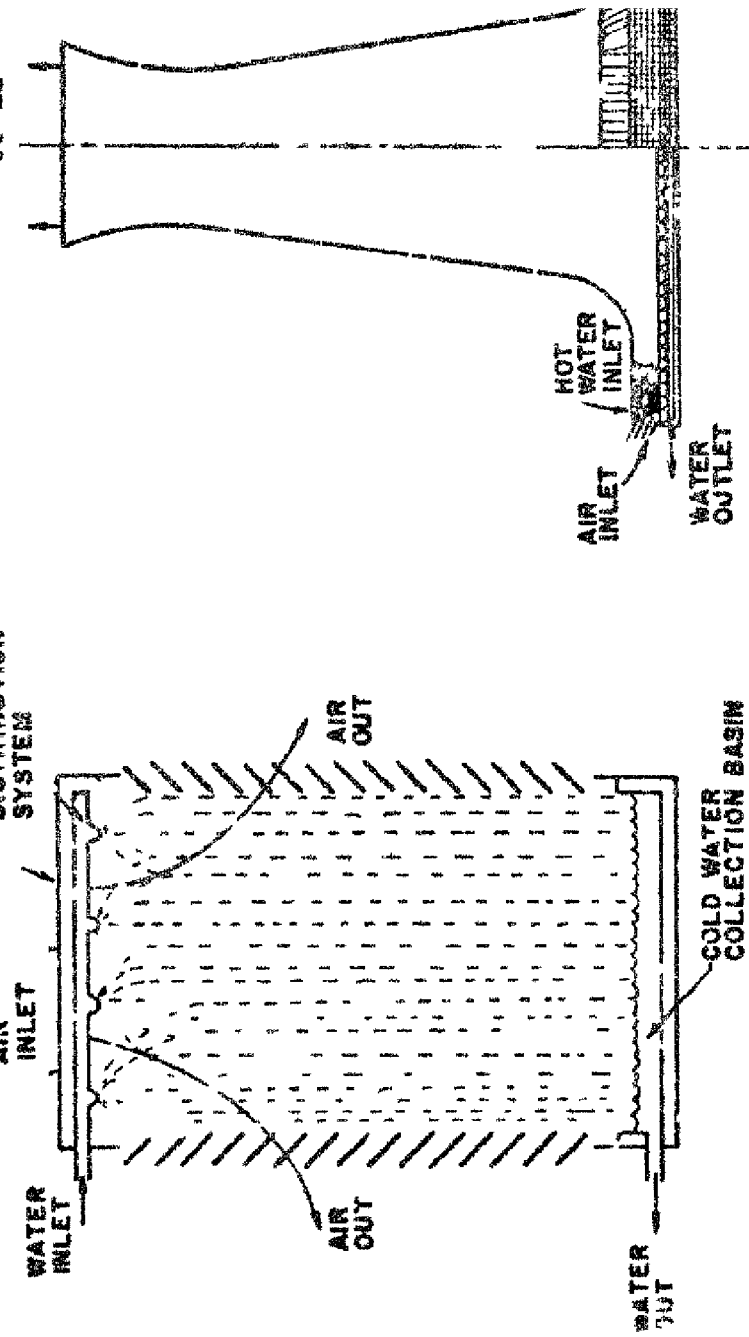
#### 2.3.2.a Natural Draft, Spray-Filled Tower [Fig. 2.2]

The spray-filled tower is essentially a compact enclosure having louvers on all sides to prevent drift losses, and tank at the bottom. Water which is sprayed downwards through nozzles, comes into contact with air flowing cross-wise as wind normally blows horizontally and gets cooled. The main components are spray system, water basin and louvers. The nozzles play an important role on the tower efficiency. The dense spray improves the efficiency and confined spray cuts the water loss.

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To ensure a uniform distribution of water and to reduce drift losses, low output nozzles pointing downwards are used.

- Advantages:
1. Light weight and small in size. The smaller space requirement enables its installation even on the roof of a building,
  2. Easy operation and maintenance,
  3. Requires very less power (only to pump water for spray),
  4. The hot air doesnot mix with fresh air,
  5. Life is trouble free and long as not many mechanical parts are involved,
  6. Since louvers are always wet, they increase water surface exposed to air.

- Disadvantages:
1. Cooling range is limited,
  2. Efficiency is low because of limited contact time and the wind losses. Not suitable for big industrial units,
  3. Water is sprayed from top, requiring more pump power,
  4. Nozzles may get clogged, requiring cleaning to avoid unbalanced water spray,

## 5. More pumping pressure - for atomization of water in a nozzle.

### 2.3.2.b Splash-Filled Natural Draft Tower:

Filling is incorporated to increase water break-up with a view to provide additional water surface to air flow apart from spray filled towers. Open louvers allow outside air to pass through tower over its full height. Despite the greater cooling efficiency than spray-filled towers, it is rarely used now-a-days because of increased initial cost and maintenance.

- Disadvantage:
1. Greater length of tower is needed to compensate for the narrow structure,
  2. Initial cost and pumping head are high,
  3. Tower's extreme length and height and narrow width necessitates good anchoring to withstand high winds.

### 2.3.2.c. Hyperbolic Towers [Fig. 2.3]

These towers are suitable for the largest heat load applications. They are built as cross flow or counter flow depending on requirement. They have a tall cylindrical structure above the spray system to provide chimney effect, the natural-draught. This draught,



The higher initial investment is balanced against savings in fan cost, fan power, longer life and less maintenance. They find their preferences as under:

1. Where geography dictates maximum height release of moist air plumes,
2. For confined, restricted area sites,
3. Where extremely high power cost make natural draft most applicable.

The hyperbolic shape of the tower is employed from the aerodynamic and practical view points, but it does not have any thermodynamic significance. The reasons for the preference of the hyperbolic shape are:

1. The cross section at the bottom, provides more space for fill and reduction in height of louvers, leading to reduction in pumping head.
2. The direction of inlet air changes from horizontal to vertical smoothly. Thus the turbulence is minimised.
3. The wind load on the structure is low due to reduced cross section at the top, where wind velocities are high.
4. Because of 'doubly curved' nature it is structurally strong as bending stresses are negligible.

5. Some what enlarged top decreases the velocity of air comparatively. The water particles in drift will be condensed due to sudden change in velocity.

- Advantages:
1. Simplicity in operation due to absence of mechanical parts,
  2. Total avoidance of heated air recirculation,
  3. High heat dissipation capacity,
  4. Absence of fan,
  5. Can be located at the middle of structural buildings as there is no ground fogging due to large height of the tower,
  6. Loss of water due to drift is negligible,
  7. Longer life.

- Disadvantage:
1. High initial cost,
  2. No control over air supply hence on outlet temperature of water.

#### 2.3.3.a. Mechanical-Forced Draft Towers [Fig. 2.4]:

The forced draught created by the fan mounted at the bottom of the tower eliminates the dependence of cooling on the wind velocity and can be controlled as per requirement. The system becomes very compact for a given heat load.

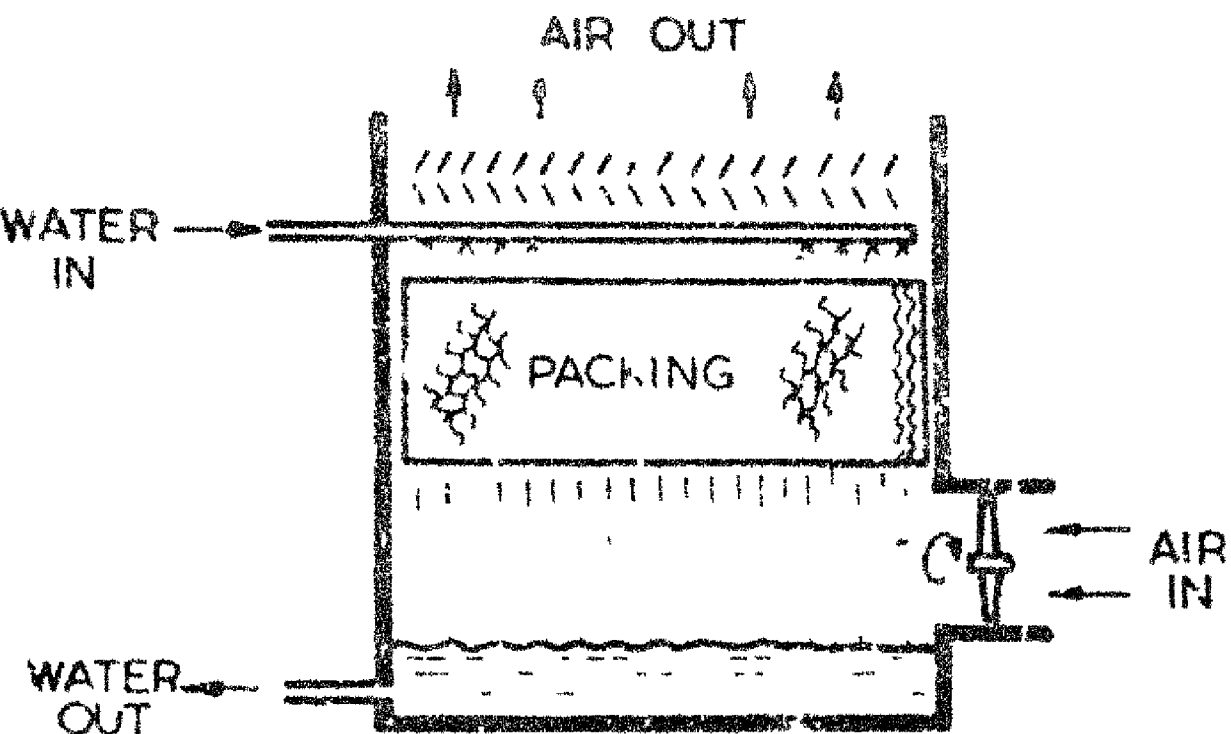


Fig 2.4 Mechanical draft tower

- Advantage:
1. Requires less space and piping than atmospheric towers,
  2. Cooling efficiency is improved,
  3. Close control of cold water temperature is possible,
  4. Fans mounted on the floor, better foundation-less vibration,
  5. Part of the velocity head is converted into pressure head and at the upper part again into velocity head, thus requiring less power,
  6. Tower is compact and more packing is possible in a given volume,
  7. Fan is not subjected to moist conditions.

- Disadvantage:
1. Operation of tower depends on fan characteristics,
  2. Limited fan size and more energy for fan,
  3. Higher operating and maintenance cost,
  4. Possibility of recirculation of hot humid air.

#### 2.3.3.b. Induced Draft Tower [Figs.2.5.a and 2.5.b]

The fan is mounted on the top of the tower, hot and humid air is pumped out of the tower creating draft

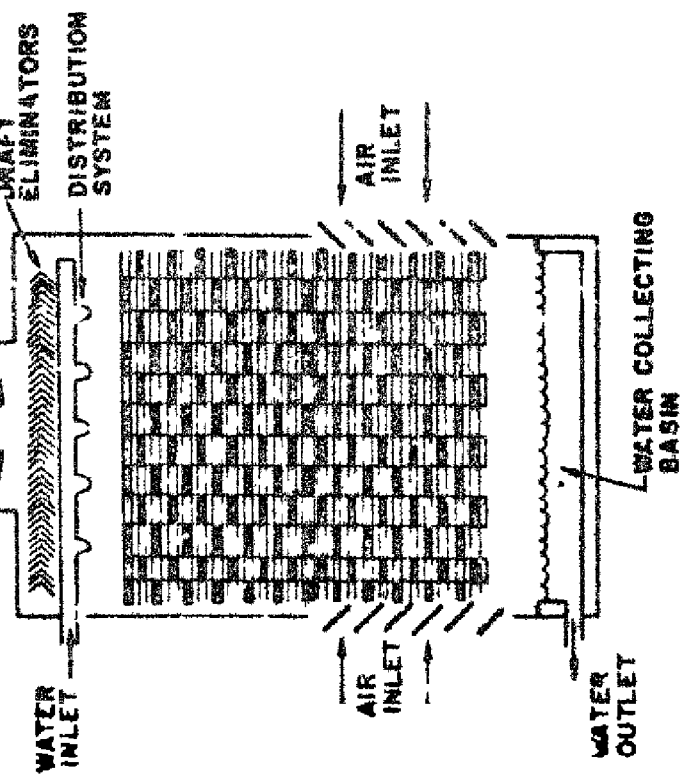


Fig 2.5.a

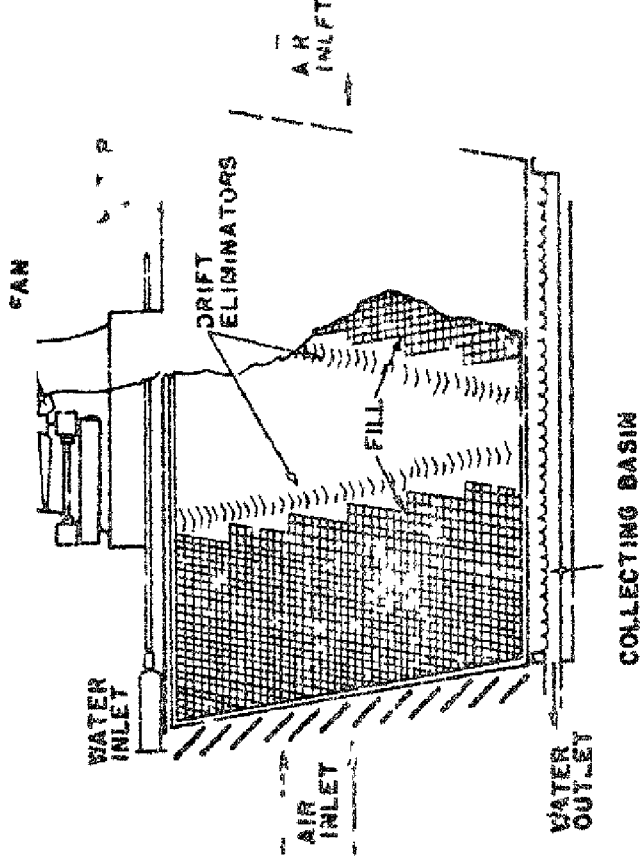


Fig 2.5.b

It is of two types

1. Counter flow,
- ii. Cross flow.

Maximum performance is achieved in induced draft counter flow tower because coldest water comes into contact with the driest air and viceversa, thereby having the maximum enthalpy gradient. In cross flow due to fill in a ring outside the tower requires lower water pumping head than in the counter flow.

Disadvantage:[Counter Flow]

1. More air resistance and uneven air distribution of air inside the tower leads to larger fan power,
2. Limited water loading and high pumping head,
3. Blower is subjected to hot and highly moistened air,
4. High maintenance cost,
5. Hot water distribution system is not easily accessible for cleaning,
6. More stronger structure is required at the top to reduce vibration,
7. The power transmission system increases cost and maintenance.

### Advantage [Cross Flow]

1. Low static pressure drop and low pumping head,
2. More filling is possible per unit volume,
3. Larger diameter of fans implies less number of cells.

### Disadvantage:

1. Design is complex,
2. Low pressure on water distribution system doesnot give fine spray,
3. Algae growth is encouraged, as water at top is exposed to atmosphere.

## 2.4 Main Components of Cooling Tower

### 2.4.1 Fill Material [17, 19]:

The cooling tower packing material is used to render as large air-water interfacial area as possible with limited air-pressure losses. The falling water on fills spreads in such a way as to provide a large surface area of contact between water and air stream. Inspite of present wide-spread and continually growing use of cooling towers, only limited information is available on the specific performance and pressure drop characteristics of cooling tower packing arrangements.

There are basically two types of packing-splash and nonsplash arrangements. The former utilise a system of laths generally of wood, variously shaped and spaced,

for the falling water to break into droplets. In the later case, drops are discouraged, and the water is caused to spread thinly over the surface of the filling. Splash type fill are generally used in cross flow designs and non-splash (film) type are utilized in counter flow designs.

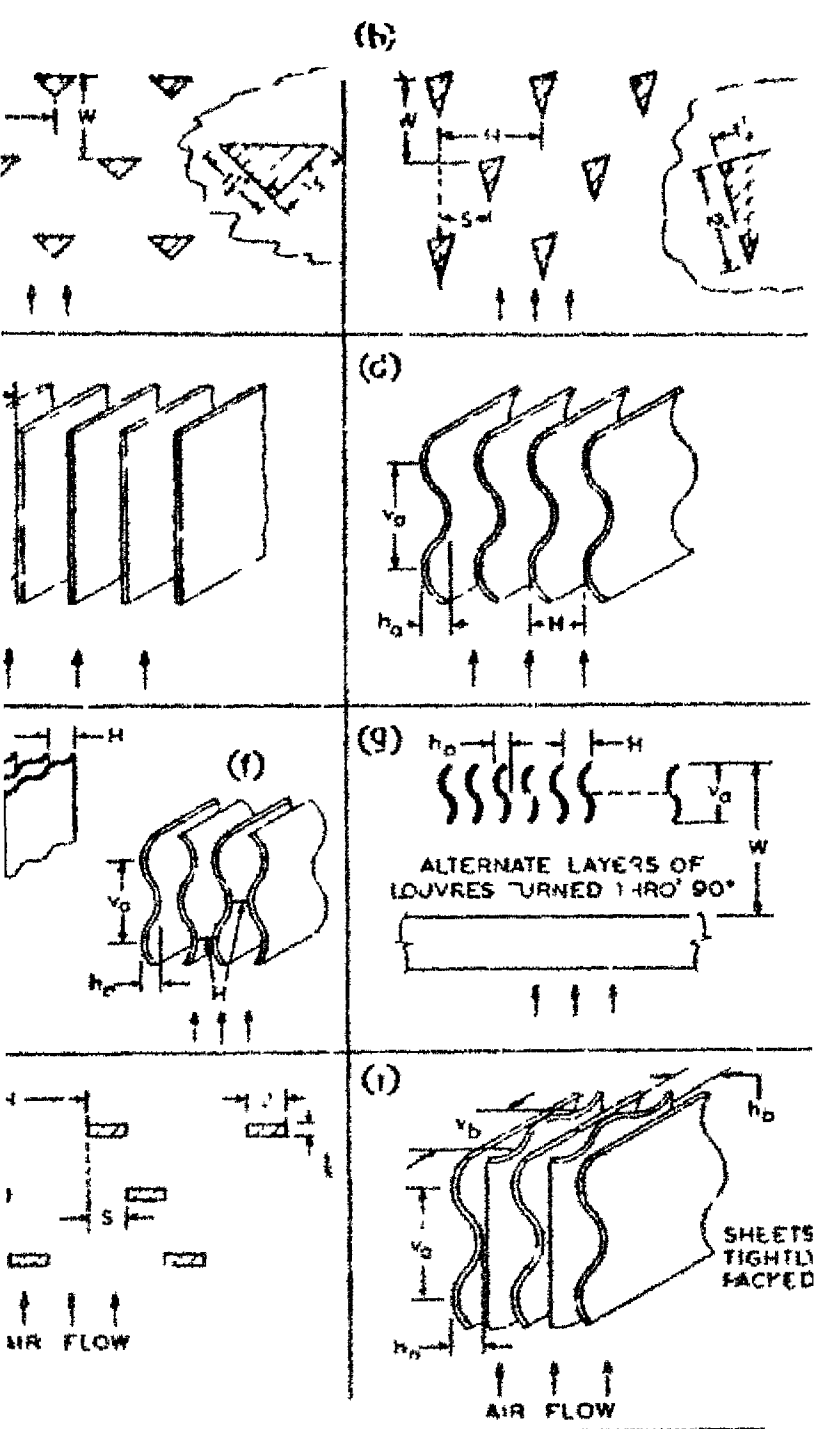
Packings can be made from a variety of materials including wooden or plastic laths, corrugated asbestos cement sheets, plastic sheets, sheets of galvanized steel, resin-impregnated paper or glass fibre [Fig. 2.6]. The factors influencing the choice of fill are heat transfer characteristics, pressure loss, total packing cost and durability which implies freedom from maintenance. Naturally a fill that has lowest cost, higher heat transfer and low pressure loss is preferred. However, the problem of selection becomes more difficult when a packing is better in one or two respects and worse in the remainder.

#### 2.4.2 Distribution System [14, 19]:

The function of distribution system is same as that of fill. Here inlet hot water is distributed uniformly over the fill section. It is of two types, gravity and spray types.

In gravity type a shallow tank or channels open to atmosphere are located on the top of the tower. Water





falls through the orifices over the tower packing due to gravity providing splash type pattern

In spray type, a header having a set of nozzles issues fine spray of water being distributed evenly over the fill. We can consider other types also in which the water is spread in a form of a thin film on the packing underneath without formation of droplets (film type).

#### 2.4.3 Circulating Pumps [14, 19]

Pumps are used to circulate hot water over top of the tower and to distribute cold water from tower to the process where its service is required. They may be of different types. The centrifugal pumps (single or multi-stage) are most commonly used. Their selection depends upon:

- a. discharge,                      b. head to be produced,
- c. efficiency,                      d. source of power,
- e. installation,                      f. maintenance,
- g. impurities in water, etc.

#### 2.4.4 Fans [14, 19]:

Fans handle large volume of air at low velocities with a low-pressure drop through the tower. Thus the fan should be economically designed to handle desired air flow at minimum input.

In induced draft towers the fans are mounted on the top of the tower they are subjected to moistened conditions. Thus the blades should be given a proper protective coating. The most popular protective coating is not dipped galvanizing. Danger from excessive vibration, both to tower and equipment must be taken care with safety device. A large decrease in efficiency results when a thin layer of dirt or ice is formed on the fan blades. A 1/3 mm thick coating may reduce 4 to 5% efficiency of fan. Even the clearance between the blade tips and fan housing has an important effect on efficiency. Thus a careful design of fan is needed.

#### 2.4.5 Fan Drives, Speed Reducers and Motors:

These are the accessories to fan. The prime function of fan drive or drive shaft is to transmit power from the prime mover i.e., motor to the gear or speed reducer. Special care has to be taken in design of these parts as because they are also operating under the same condition as that of fan. This has a direct effect on the efficiency of the fan.

MATHEMATICAL ANALYSIS3.1 Psychrometry and Heat Transfer [9, 10, 17, 24]

The determination of cooling tower performance requires the study of moist air i.e. psychrometry and heat transfer relations. The expressions for various quantities used in the present investigation have been given below.

1. Humidity ratio for unsaturated air is expressed in terms of mol-fraction of water:

$$w = 0.622 x_w / (1 - x_w) \quad (3.1.1)$$

2. Humidity ratio for saturated air:

$$w_s = 0.622 f_s p_{w,s} / (p - f_s p_{w,s}) \quad (3.1.2)$$

where  $f_s$  has been functionally related to  $T$  from the data as

$$f_s(T) = 1.004505 - 2.0707 \times 10^{-5} T + 9.1415 \times 10^{-7} T^2$$

3. Enthalpy

$$h = c_{pa,w} t + 2501.4 w \quad (3.1.3)$$

where  $c_{pa,w} = c_{pa} + 1.884 w$

4. Prandtl number

$$Pr = \frac{c_{pa} \mu}{k} \quad (3.1.4)$$

5. Reynolds number

$$Re = \rho V L / \mu \quad (3.1.5)$$

6. Heat transfer coefficient

$$h_c = \frac{0.171 k Pr}{d_e^{0.22}} \left( \frac{VSEC}{\nu} \right)^{0.78} \quad (3.1.6)$$

7. Properties of air and water in terms of temperature

$$i \quad P_{w,s} = 225.65 \times 10^{-4} \times 9.81 / [(7.21379 + (1.152 \times 10^{-4} - 4.787 \times 10^{-9} t) (t - 483.16)^2) (647.31/t-1)]$$

$$ii \quad c_{pa} = 0.219 + 0.0343 \times 10^{-4} TR - 0.297 \times 10^{-8} TR^2$$

$$iii \quad c_{pw} = 4.2097187 - 1.4125 \times 10^{-3} T + 1.375 \times 10^{-5} T^2$$

$$iv \quad h_{fg} = 597.34 - 0.555 T \\ 0.2389 \times 10^{(5.1463 - 1540/t)}$$

$$v \quad h_f = 0.99615 T + 1.8239 \times 10^{-6} T^2 \\ - 0.13468 \times 10^{(-0.036 T)} + 0.13468$$

$$vi \quad \rho_a = 1.291 - 4.525 \times 10^{-3} T + 1.125 \times 10^{-5} T^2$$

$$vii \quad \mu = 0.0207 + 8.5 \times 10^{-5} T + 1.625 \times 10^{-5} T^2$$

$$viii \quad \nu = 1.325 \times 10^{-5} + 8.525 \times 10^{-8} T \\ + 1.625 \times 10^{-10} T^2$$

These governing equations based on the heat and mass transfer principles help analyse the given tower. The following assumptions are made-

1. no water losses except evaporation,
2. no heat transfer through the walls of the tower.

They are used to get the condition on the psychometric chart, representing the changes in the state of moist air passing through the tower. The rate of evaporation depends upon the

1. molecular weight of the liquid,
2. velocity of the impressed draught,
3. relative saturation and partial vapour pressures i.e. inference upon the humidity of the circulating air,
4. surface exposed to evaporation.

### 3.2 Cross-Flow Analysis [10, 25]

In this case the air and water flows are perpendicular to each other. Water falls from top of the tower and air flows from outside of the tower. The analysis of this type is extremely involved. Because the direction of air flow will be changing constantly due to falling water droplets and packing arrangement inside the tower.

The resistance to flow of air increases thus leading pressure drop which is difficult to predict. Hence as a whole the exact nature of flow is difficult to analyze in case of cross-flow. Analysis is again done using finite element technique. The errors committed by the assumptions are minimized by selecting large number of grids. Figure 2.5.b shows a typical cross-flow cooling tower having fills and grids.

Figure 3.1 shows the element (1, j) of cross flow cooling tower under consideration for analysis with control volume (indicated by dotted lines).

$$\dot{m}_{w_{1+1,j}} = \dot{m}_{w_{1,j}} - \dot{m}_{a_{1,j}} (w_{1,j+1} - w_{1,j}) \quad (a)$$

$$T_{w_{1+1,j}} = T_{w_{1,j}} - \Delta T_{w_{1,j}} \quad (b)$$

$$h_{1,j+1} = h_{1,j} + \Delta h_{1,j} \quad (c)$$

By heat balance

$$\text{Heat gained by air} = \dot{m}_{a_{1,j}} (h_{1,j+1} - h_{1,j})$$

$$\text{Heat lost by water} = \dot{m}_{w_{1,j}} c_{pw} T_{w_{1,j}} - (\dot{m}_{w_{1+1,j}} c_{pw} T_{1+1,j})$$

Using Eq. (3.2.1.c), Eq. 3.2.3 reduces to

$$d\dot{q} = \dot{m}_{a_{1,j}} (w_{1,j+1} - w_{1,j}) c_{pw} T_{w_{1,j}} + [(\dot{m}_{w_{1,j}} - \dot{m}_{a_{1,j}} (w_{1,j+1} - w_{1,j})) c_{pw} \Delta T_{w_{1,j}}] \quad (3.2.4)$$

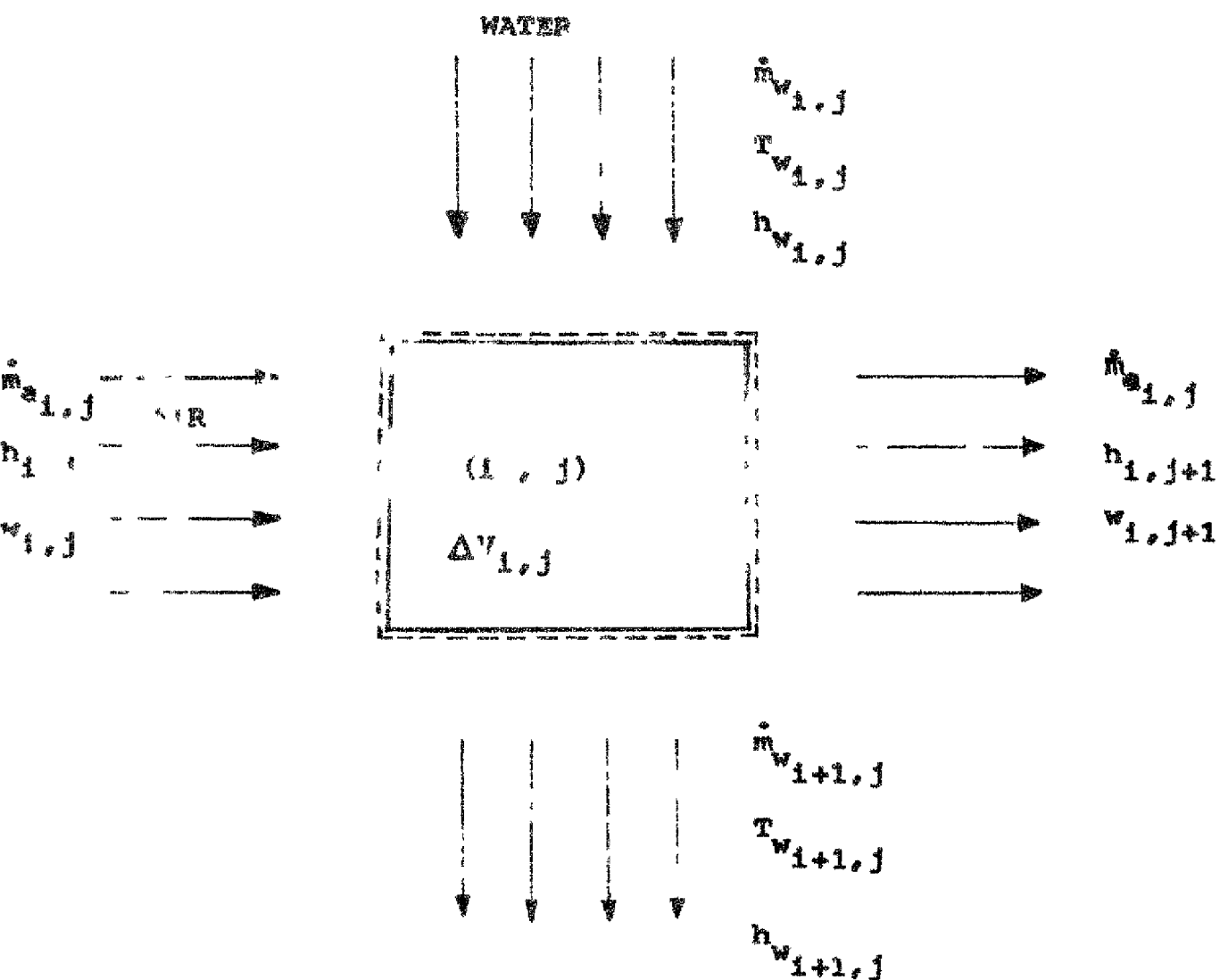


Fig. 3.1 ELEMENT  $(1, j)$  IN CROSS-FLOW WITH CONTROL VOLUME



But heat gained by air      Heat lost by water

$$d\theta = \dot{m}_{a_{1,j}} (w_{1,j+1} - w_{1,j}) c_{pw} T_{w_{1,j}} + [ \dot{m}_{w_{1,j}} c_{pw} \Delta T_{w_{1,j}} ] - \dot{m}_{a_{1,j}} (w_{1,j+1} - w_{1,j}) c_{pw} \Delta T_{w_{1,j}} \dots \quad (3.2.5)$$

Also total heat transfer = Heat transfer due to convection + Heat transfer due to mass transfer

$$\dot{m}_{a_{1,j}} (h_{1,j+1} - h_{1,j}) = h_c A_v dv_{1,j} (T_{w_{1,j}} - T_{a_{1,j}}) + h_D A_v dv_{1,j} (w_s(T_{w_{1,j}}) - w_{1,j}) h_{fg}(T_{w_{1,j}}) \dots \quad (3.2.6)$$

By mass balance

$$\dot{m}_{a_{1,j}} (w_{1,j+1} - w_{1,j}) = h_D A_v dv_{1,j} (w_s(T_{w_{1,j}}) - w_{1,j}) \quad (3.2.7)$$

Rewriting Eq. (3.2.6)

$$- \dot{m}_{w_{1,j}} c_{pw} dT_{w_{1,j}} = h_D A_v dv_{1,j} [ Le c_{pa} (T_{w_{1,j}} - T_{i,j}) + (w_s(T_{w_{1,j}}) - w_{1,j}) h_{fg}(T_{w_{1,j}}) ] \quad (3.2.8)$$

Combining Eqs. (3.2.5, 3.2.7 and 3.2.8) and neglecting smaller values

$$\frac{dh_{i,j}}{dw_{i,j}} = Le c_{pa} \frac{(T_{w_{1,j}} - T_{i,j})}{(w_s(T_{w_{1,j}}) - w_{1,j})} + h_g(T_{w_{1,j}}) \dots \quad (3.2.9)$$

Using the relations between enthalpy, temperature, specific heat and humidity, we can write

$$\begin{aligned} (h_{s(T_{w_{1,j}})} - h_{1,j}) &= c_{pw} (T_{w_{1,j}} - T_{1,j}) + 2501.4 \\ (w_{s(T_{w_{1,j}})} - w_{1,j}) & \end{aligned} \quad (3.2.10)$$

Combining Eqs. (3.2.9 and 3.2.10)

$$\frac{dh_{1,j}}{dw_{1,j}} = Le \frac{(h_{s(T_{w_{1,j}})} - h_{1,j})}{(w_{s(T_{w_{1,j}})} - w_{1,j})} + h_{g(T_{w_{1,j}})} - 2501.4 \quad Le \quad \dots \quad (3.2.11)$$

Equation 3.2.11 gives the relation for the condition line of the heat and mass transfer process. It can be plotted on the psychometric chart after evaluation for a given set of operating conditions as shown in Fig. 3.2.

Rewriting Eq. (3.2.5),

$$dT_{w_{1,j}} = \frac{\dot{m}_{a_{1,j}} (dh_{1,j} - dw_{1,j} h_{f,w_{1,j}})}{(\dot{m}_{w_{1,j}} - \dot{m}_{a_{1,j}} dw_{1,j}) c_{pw}} \quad (3.2.12)$$

$$dv_{1,j} = \frac{\dot{m}_{a_{1,j}}}{h_D A_V} \left[ \frac{dw_{1,j}}{w_{s(T_{w_{1,j}})} - w_{1,j}} \right] \quad (3.2.13)$$

Total volume can be written as:

$$V = \sum_{i=1}^M \left( \sum_{j=1}^N dv_{1,j} \right) = \sum_{i,j} \frac{\dot{m}_{a_{1,j}}}{h_D A_V} \left( \frac{dw_{1,j}}{w_{s(T_{w_{1,j}})} - w_{1,j}} \right) \quad \dots \quad (3.2.14)$$

Equations (3.2.11, 3.2.12 and 3.2.14) forms the governing differential equations of cross flow tower analysis.

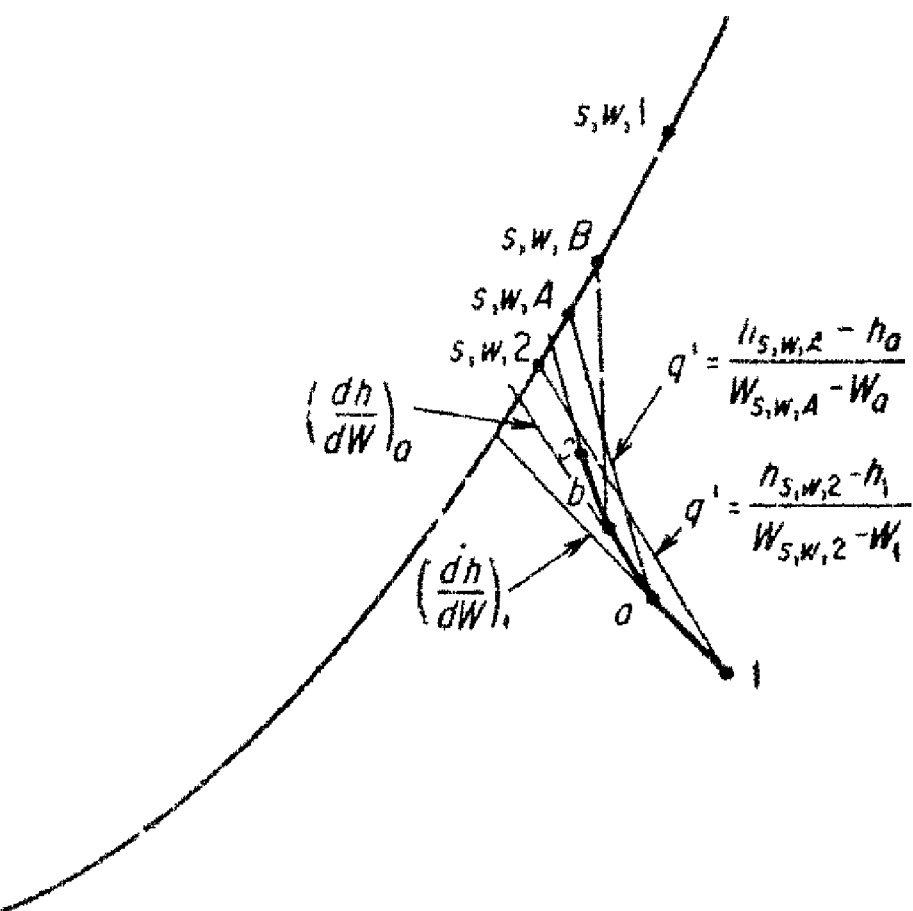


Fig 3.2 Condition line for cooling tower on psychometric chart

### 3.3 Counter-Flow Anal is

#### 1. With evaporation loss

Water and air move in opposite directions parallel to each other. The whole tower is divided into number of sections for stepwise integration. In this case the flow is one dimensional. Proceeding in the similar way as in case of cross-flow analysis, we get the following governing equations:

$$\frac{dh}{dw} = Le \frac{(h_{s,w} - h)}{(w_{s,w} - w)} + (h_{g,w} - 2501.4 Le) \quad (3.3.1)$$

$$- \Delta t_w = \frac{\dot{m}_a}{\dot{m}_w c_{pw}} (\Delta h - \Delta w h_{f,w}) \quad (3.3.2)$$

$$dv = \frac{\dot{m}_a}{h_D A_v} \left( \frac{dw}{w_{s,w} - w} \right) \quad (3.3.3)$$

$$\text{Thus total volume } V = \int dv = \frac{\dot{m}_a}{h_D A_v} \int_{w_1}^{w_2} \left( \frac{dw}{w_{s,w} - w} \right) \quad (3.3.4)$$

Eq. (3.3.1) gives the condition line on psychometric chart for various points in the tower. Equations (3.3.1, 3.3.2 and 3.3.4) will form the governing differential equations for the cooling process in the counter-flow tower.

#### ii. Without evaporation loss:

Here the analysis is similar as that of 3.3.i.

But the following changes are noted

$$a. \dot{m}_{w0} = \dot{m}_{w1}$$

$$b. \dot{m}_a dh = \dot{m}_f dh_{f,w}$$

$$c. \frac{dh}{dw} Le = \frac{(n_{s,w} - h)}{v_{s,w} - v} + (h_{fg,w} - 2501.4 Le)$$

### 3.4 Tower Characteristic and Number of Transfer Unit [4, 6, 18]

The sensible and latent heat transfer are combined into an overall process based on enthalpy potential as driving force. An equivalent heat transfer coefficient has been chosen to represent the combined effects of heat and mass transfer coefficients. The basic equation based on heat transfer to air by water can be written as

$$\dot{m}_a dh = k_e A V (h_{s,w} - h) = \dot{m}_w dT \quad (3.4.1)$$

Therefore, we can write

$$k_e A V / \dot{m}_a = \int dh / (h_{s,w} - h) \quad (3.4.2)$$

$$= k_e A V / \dot{m}_w = \int dT / (h_{s,w} - h) \quad (3.4.3)$$

The dimensionless number on <sup>the</sup> left hand side of Eqs. (3.4.2 and 3.4.3) are known as "NUMBER OF TRANSFER UNIT" and "TOWER CHARACTERISTICS" respectively. It is found that tower characteristic is less accurate than number of transfer units. Thus, in practice, the given tower is analysed based on Eq. (3.4.2).

### 3.5 Volume of Tower Based on Water Evaporation Rate [2, 10, 24, 31]

Equations (3.2.13 and 3.3.3) give the volume at each element and the total volume of tower is given by

Eqs. (3.2.14 and 3.3.4) for cross flow and counter flow, respectively. For the cross-flow we calculate the volume based on mean values of humidity and humidity difference.

$$\begin{aligned}
 \text{i.e. } V &= \sum_{i=1}^M \left( \sum_{j=1}^N dv_{i,j} \right) = \sum_{i=1}^M \sum_{j=1}^N \frac{\dot{m}_{a_{i,j}}}{h_D A_v} \\
 &\quad \left[ \frac{(dw_{1,j} + dw_{1,j+1})}{4} (1/(w_{s(T_{w_{1,j}})}) - w_{1,j}) \right. \\
 &\quad \left. + 1/(w_{s(T_{w_{1,j+1}})}) - w_{1,j+1} \right] \quad (3.5.1)
 \end{aligned}$$

### 3.6 Procedure of Solving Problems in Cooling Towers [10, 18, 24]

#### 3.6.1 Cross-Flow:

The water inlet condition for all elements in first row and air inlet condition for all elements in first column are known. Thus, for the element (1,1) we know all the inlet conditions. Hence we can calculate the outlet conditions of air and water from Eqs. (3.2.11 and 3.2.12). As the motion of air and water are at 90° to each other the outlet condition of air will be inlet condition of air for element (1,2). Thus, for element (1,2) we know both air and water inlet conditions and we can carry out the analysis for all the elements in the first row. The Lewis number is calculated at an average condition.

The water temperatures at exit for each element of the first row are known from Eq. (3.2.12). For the second row computation is repeated. This method is followed until all the rows are completed giving exit state of water for each column. Further, volume of cooling tower is calculated using Eq. (3.2.14).

The average outlet condition of water is found from the following equation:

$$T_{w,av} = \frac{\sum_{j=1}^N T_{w,M+1,j}}{N} \quad (3.6.1)$$

Similarly, the average outlet condition of air at exit is given by

$$h_{a,av} = \frac{\sum_{i=1}^M h_{i,N+1}}{M} \quad (3.6.2)$$

$$w_{a,av} = \frac{\sum_{i=1}^M w_{i,N+1}}{M} \quad (3.6.3)$$

### 3.6.2 Counter Flow:

In this type of towers Eqs. (3.3.1, 3.3.2 and 3.3.4) forms the governing equations of the process, and are solved for the given inlet and desired exit conditions of water, which gives desired range. As flow rate remains the same throughout the tower the range is equally divided as the number of divisions of the tower. This forms the required change in water temperature ( $dT$ ) at each stage.

For the determination of the size of the tower or the tower characteristics, a numerical method is applied by dividing it into a number of sections. Stepwise integration is carried out from the bottom of the tower until the exit state of air is determined. In this way for known values at various state points, the size of the cooling tower is determined using Eq. (3.4.2). Knowing all the values in Eq. (3.3.1), we can determine the value of  $dh/dw$ . Further, we know  $\Delta T_w$ . Thus from Eqs. (3.3.1 and 3.1.14) we have two unknowns  $dh$  and  $dw$ , which can be solved. Thus the value at the exit of that division is calculated. And the analysis is continued until the exit values are calculated.

### 3.7 Variable Lewis Number [10, 23]

As stated earlier, it gives a relationship between heat transfer and mass transfer coefficients in a dimensionless form named after the discoverer, Prof. Lewis, W.K. (1922). Its value depends on the velocity of air flow, dry-and wet-bulb temperatures of air and water (inlet) temperature. It can be represented as

$$Le = f(V, T_{db}, T_{wb}, T_w) \quad (3.7.1)$$

A generalized relation for Lewis number is given by:

$$F(VMIN) = 0.333(\log_{10} VMIN)^2 + 0.177046 \log_{10} VMIN + 2.6949 \times 10^{-3} \quad (3.7.2)$$



$$GH = 4.32 \times 10^{-4} (T_1 + T_w)/2 + 0.8444^a \quad (3.7.3)$$

$$C = 0.75 \times GH + 0.25 \quad (3.7.4)$$

$$M = 0.0964284 - 0.096726 \times GH \quad (3.7.5)$$

$$Le = h_c / (h_D c_{pa}) = C + M \times F(VMIN) \quad (3.7.6)$$

The graphical representation of the same is available in [10].

### 3.8 Rate of Evaporation [10]

Here the mass of water evaporated in the process of cooling can be written as

$$\dot{m}_{ev} = \sum_{i=1}^M \dot{m}_{a1,N+1} (w_{1,N+1} - w_{1,1}) \quad (3.8.1)$$

$$\text{and in percentage } \dot{m}_{re} = (\dot{m}_{ev} / \dot{m}_w) 100 \quad (3.8.2)$$

### 3.9 Variable Cost Analysis [28]

1. Fan Power: The fan used should be of optimum size. It should handle the required volume of air against the resistance to flow. It is estimated on basis of pressure drop occurring during the process. The equation used is due to work of Kelly, N.W. and Swenson, L.K., where the total pressure drop is given by the sum of pressure drop due to fills and pressure drop due to falling water droplets, i.e.

$$\Delta P = \left[ C_1 n \rho_a v_r^2 + 6C_2 n \rho_a v_r^2 \left( (\dot{m}_w / A (2 z_F / g)^{1/2}) / (3600 D_c \rho_w) \right) \right] / 2g \quad (3.9.1)$$

which is put in the following form

$$\Delta P = 25.4 n \left[ \rho_{av} / \rho_w (C3 \dot{m}_a^2 + C4 \sqrt{Z_f} \dot{m}_w GE^2) \right] \quad (3.9.2)$$

where

$$GE^2 = \dot{m}_a^2 + \frac{4}{3} \dot{m}_a 3600 \rho_a \sqrt{2g Z_f} + g (3600 \rho_a)^2 Z_f \quad (3.9.3)$$

The values of C3 and C4 is given in Table 3.1 for the different fill arrangement shown in Fig. 2.6.

$$\text{Fan power} = (\Delta P (g/g_c) \rho_w \text{ VOLSEC})/1000 \quad (3.9.4)$$

$$\text{Cost of power/year} = \text{POWFAN} \times \text{HR} \times \text{OF} \times \text{COP} (X) \quad (3.9.5)$$

Cost of power/KW-hr is given by equation:

$$\text{COP} (X) = 1.2930 / (0.97986 + e^{-0.09338 X}) \quad (3.9.6)$$

$$\text{and } X = \text{current year} - 1983 \quad (3.9.7)$$

where Eq. (3.9.6) is derived based on the cost variation of power for past 15 years. The value of further years are predicted using Powell's method of optimization with current year as reference.

2. Water Cost: Total water circulated/hr = Initial water  
+ Evaporation losses + Blow down + leakage

From Eq. (3.8.1) we know mass of water evaporated per hour.

$$\therefore \text{TOTWAT} = (\dot{m}_w (\dot{m}_{re} + \text{BLD} + \text{LKG} + \text{OTH}) \text{ HR OF})/100 \quad (3.9.8)$$

$$\text{CWAT} = \text{TOTWAT WATCOST} \quad (3.9.9)$$

3. Wood Cost:

$$\text{VOLF} = \text{Cross-section area of fill} \times \text{length of fill}$$

$$\dots \quad (3.9.10)$$

TABLE 3.1

CONSTANTS C3 AND C4 FROM EXPERIMENTAL RESULTS

DECK	VERTICAL SPACING	PLAN SOLIDITY FACTOR	VERTICAL FREE FALL ZF	C3 $\times 10^8$	C4 $\times 10^{12}$
A	0.75	0.250	3.00	0.34	0.11
B	1.00	0.250	4.00	0.34	0.11
C	1.25	0.333	3.75	0.40	0.14
D	2.00	0.333	6.00	0.40	0.14
E	2.00	0.404	4.95	0.60	0.15
F	2.00	0.219	9.13	0.26	0.07
G	2.00	0.292	6.85	0.40	0.10
H	2.00	0.550	3.64	0.75	0.26
I	2.00	0.440	4.50	0.52	0.16

4. Cost of Pumping Water Here actual head of pumping is assumed to be height of tower plus a meter.

Thus HEAD = Actual head + frictional head due to

pipe friction

$$= (HIG + a + f_r \frac{(HIG + a) v_{wat}^2}{2g d_{rip}}) \quad (3.9.12)$$

where a = 1 meter and

$$d_{rip} = [4\dot{m}_w / (\rho_w v_{wat} X)]^{1/2} \quad (3.9.13)$$

$$\therefore PPOW = HEAD \dot{m}_w g \quad (3.9.14)$$

$$PUMCOS = PPOW \text{ HR OF COP } (X) \quad (3.9.15)$$

### 3.10 Present Worth Method [28]

The unit value of costs is not identical different periods due to inter-temporal effects. This gives rise to the problem of reducing the costs to a particular base year and to make them commensurate with each other. The removal of these drawbacks gave rise to net present value approaches which can be expressed as

$$C_o = \sum_{LIFE=0}^{LIFE} \frac{C_t}{(1 + r_{int})^{LIFE}} \quad (3.10.1)$$

Equation (3.10.1) can be used for all the running expenditures.

RESULT AND DISCUSSION4.1 Selection of Grid Size

The grid size in the present computation has been selected after comparing the results for different combinations as given in Table 4.1. In case of 20 X 20 grid combination the time taken is 78% where the same result is obtained. From comparison with other combinations it is evident that 15 X 15 is the most desirable combination. It has been used for all other computations in the present investigation. Figure 4.1 shows the same graphically.

4.2 Iterative Scheme of Analysis

A generalized computer program is envisaged with a view to incorporate various constraints such as approach, range, water load, air flow rate, air inlet temperature etc. covering all practical ranges. Outlet water temperature and state of air is studied at every grid point for a typical cooling tower. The whole result can be represented in a tabular form as shown in Table 4.2. It is interesting to note that the

1000  
1000

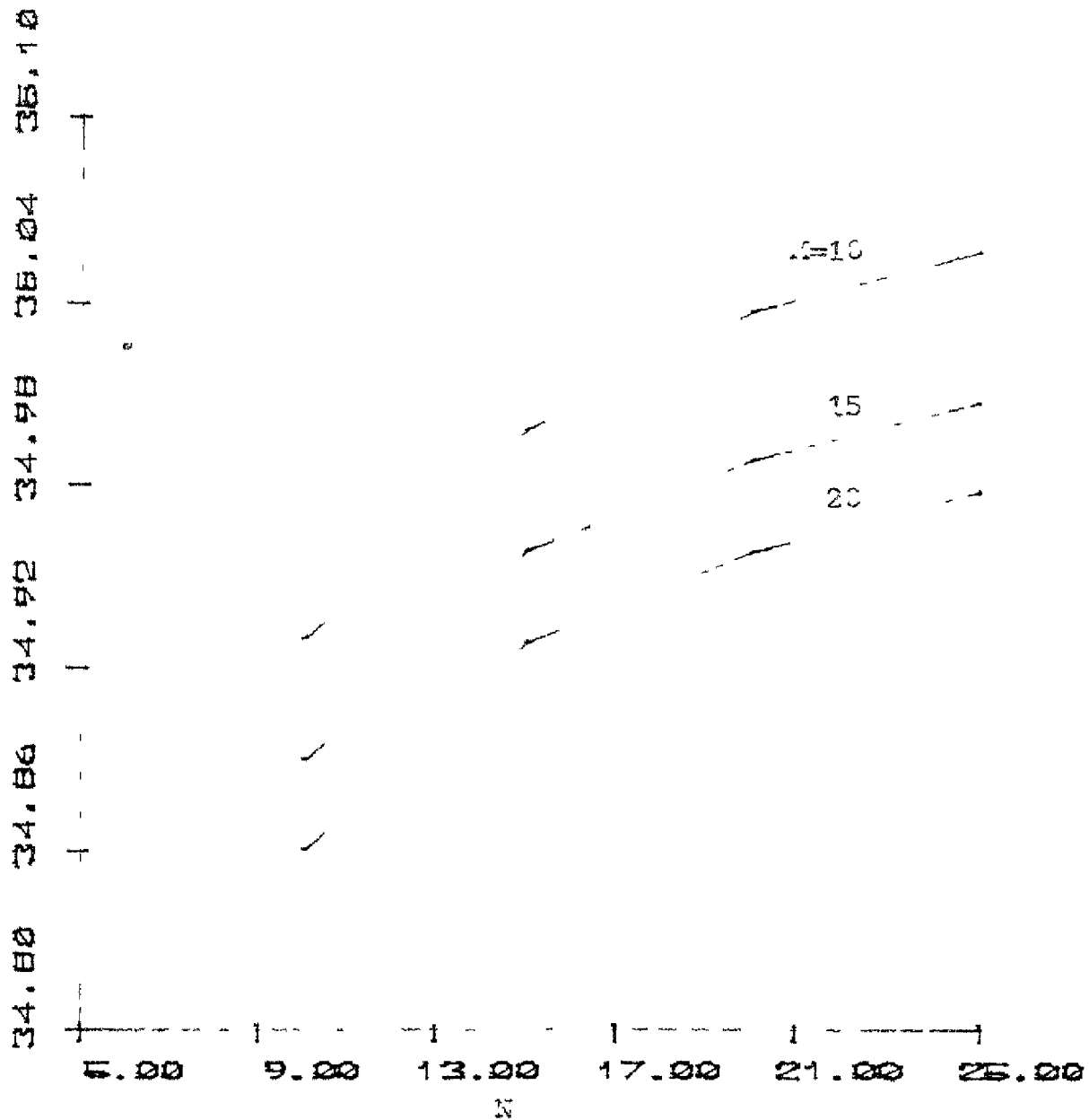


Fig 4.1 Grid selection

amount of heat transfer ed is very high for the grids

near the top and it falls as we proceed towards basin as shown in Figs.4.2 to 4.4.

A desired outlet temperature of water was obtained using an iterative scheme for a given set of inlet conditions, size of tower by varying fills in order to change the surface area. The changes in fill is continued until the desired result is achieved. Table 4.3 gives the details of temperature profile through the tower developed after 5 iterative schemes.

We should have a free fall path for water droplet for heat transfer process. By increasing the number of fill material in a given size of tower means decreasing the free fall path. To incorporate this optimum free fall path iteration is terminated if it falls below minimum path. These are shown in Table 4.4 where iterations are carried out for different water flow rates.

In counter-flow this type of iterative analysis is not necessary. Here the desired output is obtained against the tower size. If we find that the tower is smaller for given conditions, the iteration is terminated and analysed for bigger size of tower and different flow rates.

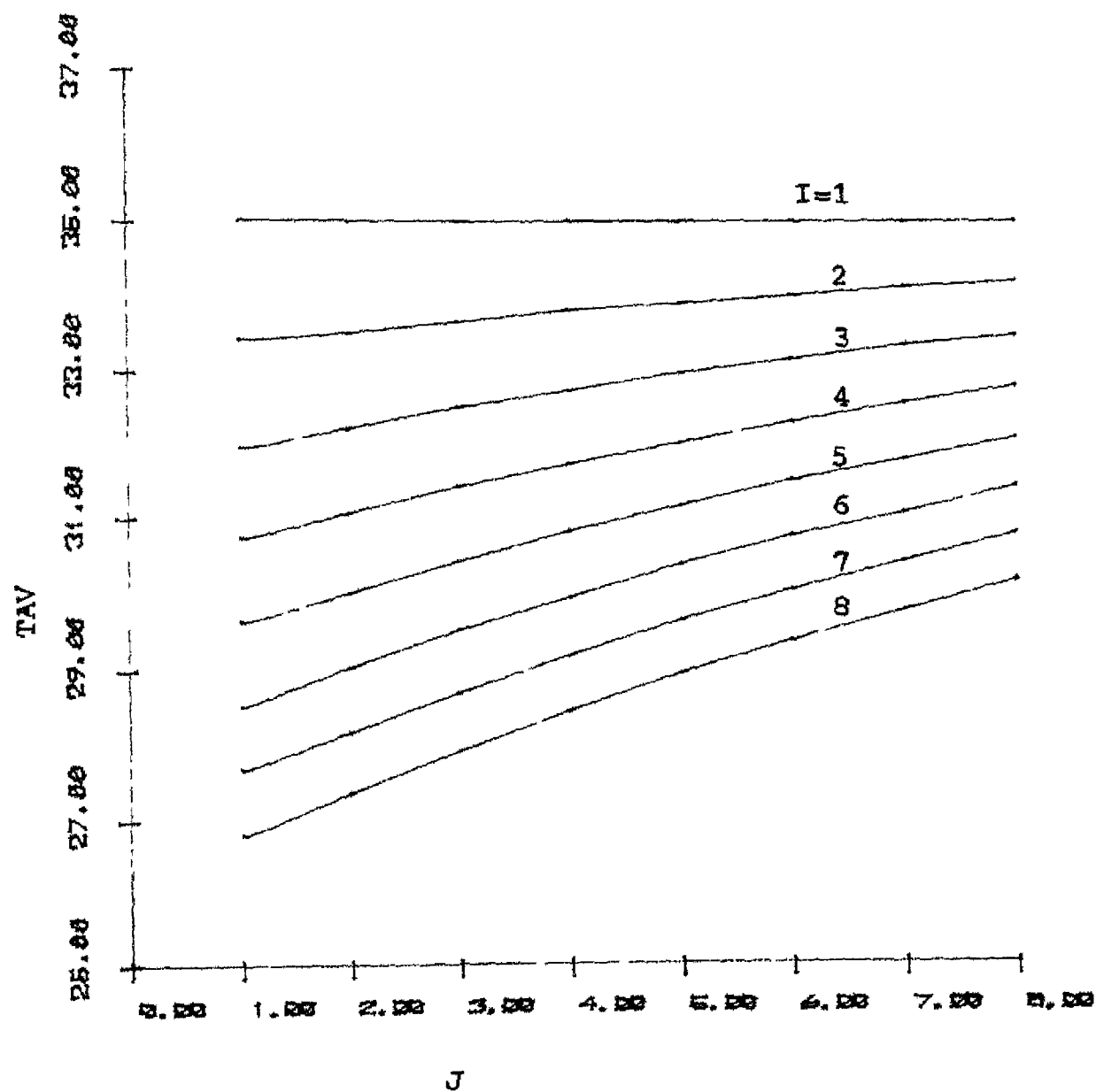


Fig 4.2 Variation of water temperature in each grid



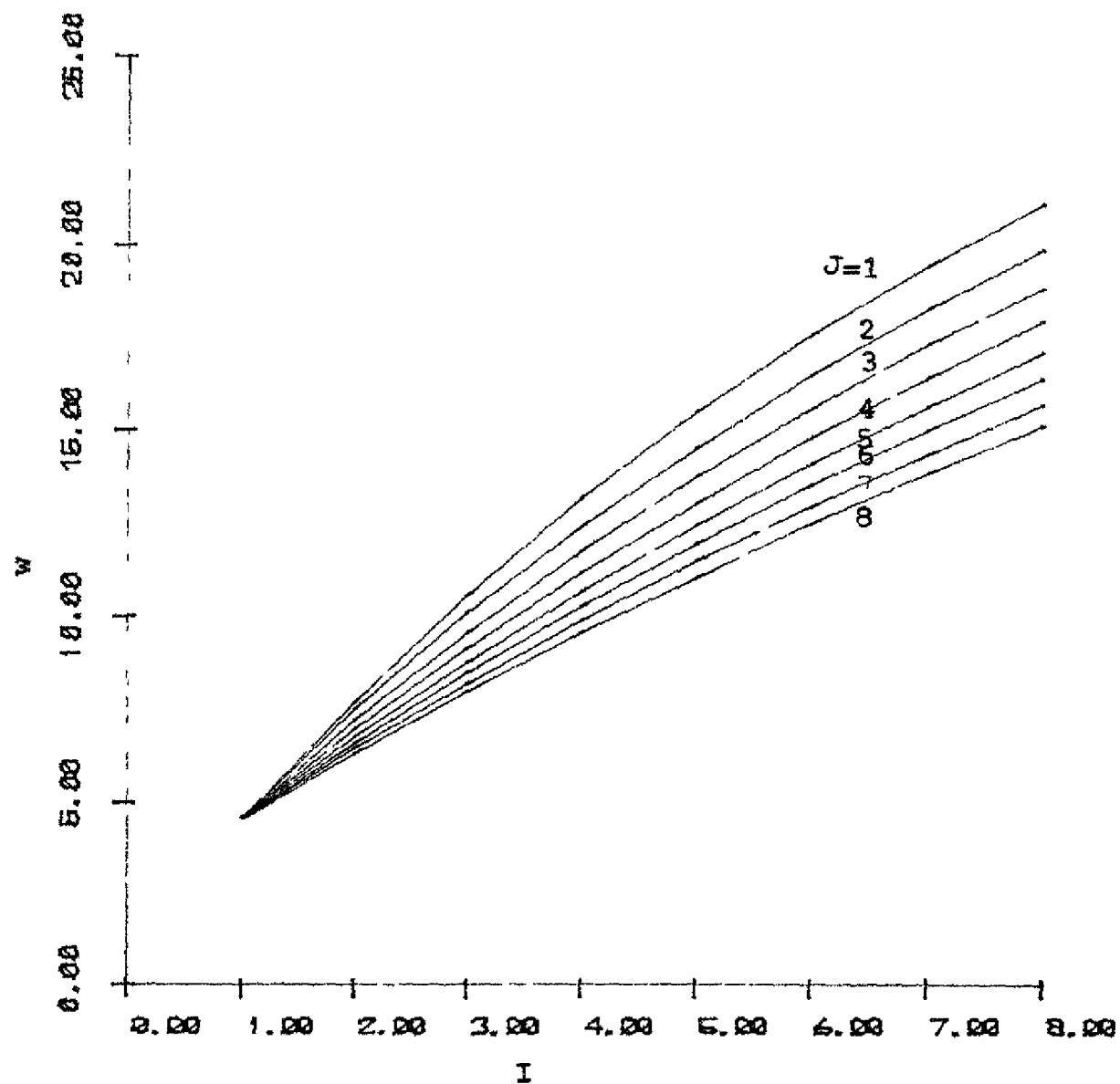


Fig 4.3 Variation of humidity of air in each grid

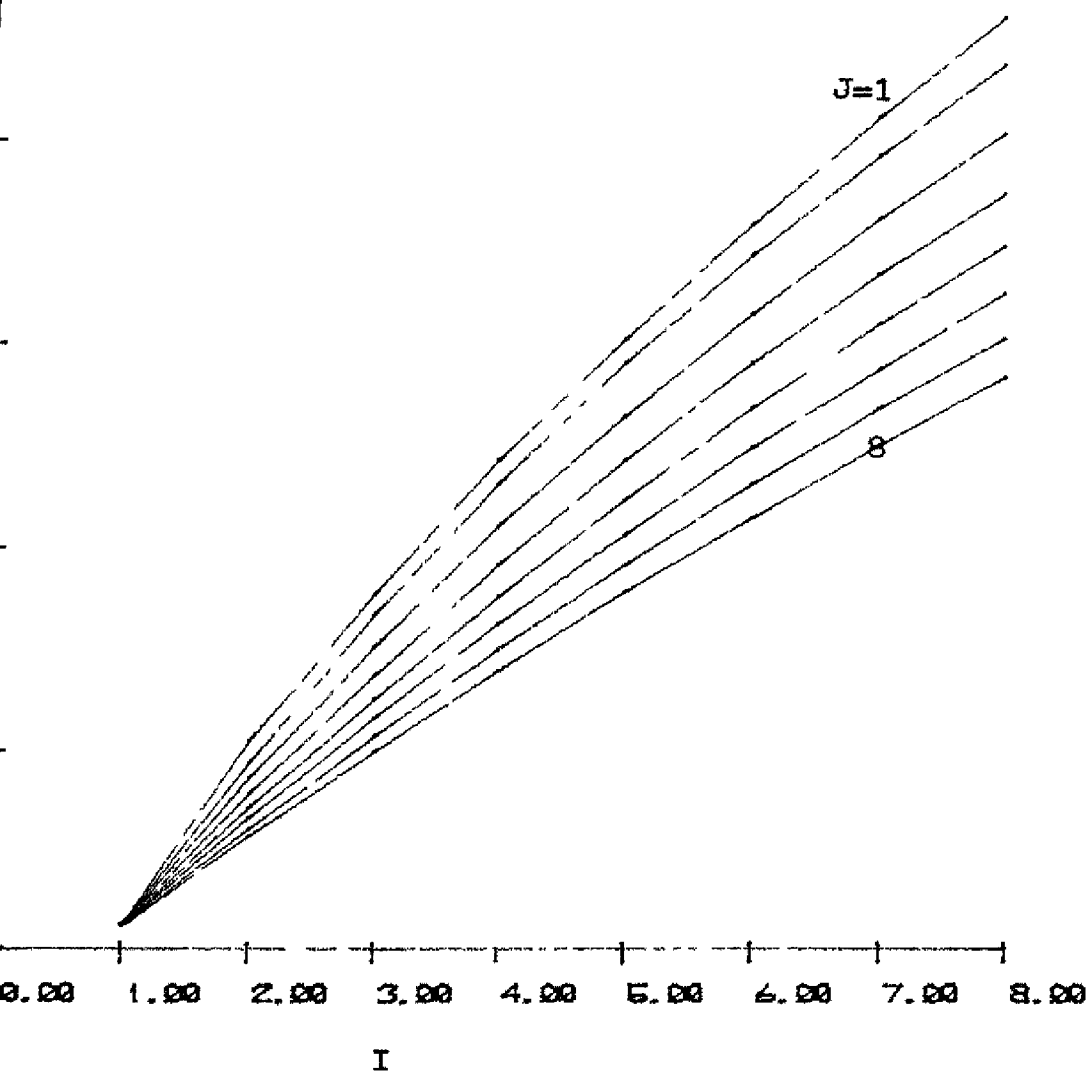


Fig 4.4 Variation of enthalpy of air in each grid

During this process the following results were noticed

1. To get a desired temperature higher by 2-5°C, than that for a given packing design, air flow rate has to be increased nearly 10 times the normal rate leading to larger fan size and its power.
2. If the difference between wet and dry bulb temperatures of air is less initially major part of heat transfer occurs due to evaporation and later the process is due to condensation.

#### 4.3 Effect of Lewis Number

Lewis number is a function of inlet air velocity, dry and wet bulb temperature and inlet water temperature. Thus a change in Lewis number will have a direct effect on the final results. Its effect is studied for two sets of values and are presented in Table 4.5.a and 4.5.b. Change of about 2-4% in final result is found for a change in recommended Lewis number from 0.84 to 0.94. In order to get rid of this discrepancy variable Lewis number has been used as given by Eqs. (3.7.1 to 3.7.6

#### 4.4 Tower Coefficients

The NTU serves as a measure in determining the tower performance. Tables (4.6.a to 4.6.d) reveals that NTU depends significantly on air flow rate as well as water

loading. Thus, NTU is a function of cooling factor as reported by [17].

The NTU method does not lend to complete mathematical solution. It is used as a verification method along with usual procedure of heat and mass transfer process. The cooling towers are specified in terms of  $\dot{m}_w$ , T1, T2, T3, DEST.V. For a particular conditions the NTU and tower characteristic will be specified. This is known as required co-efficient. For various air flow rate we can determine the above co-efficients known as actual co-efficient as shown in Table (4.6.a to 4.6.d). Thus we can select a tower and flow rate such that the required size of tower.

Tables (4.6.a to 4.6.d) exhibits decrease in the tower coefficients with increase in range. Further the coefficients becomes negative at lower rate due to occurrence of condensation against evaporation. The details of calculating tower coefficients is shown in Table 4.7. In case of cross flow the variation in coefficients is shown in Table 4.8.

#### 4.5 Volume, Heat Transfer and Evaporation in Tower Analysis

Tables 4-9 and 4-10 displays the comparison between the given volume of tower and estimated volume

Fan power cost is calculated based on the pressure drop that is occurring in the tower. Fan power and pump power are combined together and estimated for various values of flow rates. Pump power is evaluated using the discharge rate and pumping head. The total cost for power is then found from Eqs. (3.9.6 and 3.9.15).

The cost variation for different flow rate are given in Table 4.11. It is found that the cost of water dominates among other costs. The fill cost is seen to be very less but even slight change in the fill influences the pumping cost considerably. All the values have been estimated based on the optimum number for given exit water condition.

#### 4.7 Conclusions and Suggestions

A. Conclusions • From the present work the following conclusions can be derived:

1. The recommended grid size for the cross-flow cooling tower is 15 X 15 in view of saving of computational timing.
2. The effect of evaporation of water has to be considered while computing heat load capacity of the tower. Because it shows 6 to 8% higher values over the fixed mass results.

2. The effects of the recommended Lewis number are significant. Hence variable/average Lewis number suggested in the present paper be used.
3. The cost analysis shows that the make up water dominates over all other costs. This requires special care in the design aspect of a cooling tower. The present worth method has been used for the total cost.
4. For counter-flow tower the effects for evaporation of water on the exit temperature is also found to be in the same range as found for a cross-flow cooling tower.

#### B. Suggestions:

1. Better experimental data are required for heat and mass transfer coefficients for the solution of governing equations.
2. Further costs of various components of cooling tower should be collected from manufacturers for the exact cost analysis.

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TABLE 4.1 Average outlet water temperature  
v/s jet size

INLET CONDITIONS:  $T_1=45^\circ\text{C}$   
 $T_2=28^\circ\text{C}$   
 $T_3=50^\circ\text{C}$

$m_w=30,000\text{ kg/hr}$   
 $V=2.5\text{ m/sec}$

$M \backslash Z$	5	10	15	20	25
10	34.12	34.93	35.00	35.04	35.06
15		34.89	34.96	34.99	35.01
20		34.86	34.93	34.95	34.98

月 日 午 時 分  
 庚 子 年 丁 未 月 己 未 日 庚 申 時

1990

```

Temperature of Air      = 30.00 °C
Temperature of air      = 15.00 °C
Temperature on to the tower
water lead to the tower = 35.00 °C
air blown               = 30000.0 kg/hr
v or entering air      = 38976.1 kg/hr
v of entering air      = 41.28 kg
v of entering air      = 0.004508 kg/kg of dry

```

35.000	35.000	35.000	35.000	35.000	35.000
17.753	10.672	13.297	15.658	17.781	10.691
47.043	55.055	63.421	70.125	70.144	81.552
33.523	33.670	33.814	33.935	34.043	34.141
17.524	10.157	14.558	14.744	10.736	18.548
49.543	56.727	63.274	69.236	74.665	79.609
32.254	32.518	32.757	32.973	33.168	33.344
17.234	9.652	11.677	13.923	15.805	17.535
46.034	55.130	61.132	66.655	71.745	76.433
31.037	31.453	31.775	32.009	32.335	32.578
0.395	9.220	11.390	13.221	15.002	16.654
47.381	53.791	59.391	64.430	69.204	73.616
30.112	30.171	30.852	31.219	31.545	31.843
0.725	0.869	10.800	12.614	14.303	15.860
47.235	52.647	57.719	62.491	66.974	71.182
29.070	29.563	30.004	30.419	30.795	31.139
0.625	8.500	10.378	12.086	13.690	15.197
40.087	51.642	52.339	60.789	65.002	68.989
28.107	28.722	29.213	29.606	30.087	30.466
0.478	8.292	10.005	11.622	13.148	14.580
40.208	50.700	55.174	59.282	63.246	67.025
27.368	27.949	28.468	28.955	29.406	29.823
0.351	8.058	9.677	11.211	12.666	14.046
40.789	49.999	54.049	57.940	61.075	65.257

$$f_{LV} \text{ at each grid} = N \times 1000$$

717 3

```

Temperature of leaving water      = 27.96 C
enthalpy of leaving air           = 80.81 kJ
v of leaving air                  = 0.019418 kg/kg of dry

```

total suspended	=	581.1 kg/hr
total	=	1540869.4 kg/hr
of total required	=	292
of total required on		
circulation rate	=	6.8250 y**3

# 4. Details of water temperature at every grid point \*\*\*\*\*

2025011402 TAT=1528+10 PR=354E+02  
 2025011402 RA=0.4508E+00

## 1. Water temperature at every grid point

35.000	35.000	35.000	35.000	35.000	35.000	35.000
33.753	33.868	33.957	34.037	34.140	34.215	34.284
32.000	32.823	33.005	33.171	33.323	33.463	33.581
31.500	31.657	32.108	32.336	32.547	32.742	32.921
31.000	31.000	31.250	31.540	31.811	32.052	32.276
30.740	30.124	30.478	30.806	31.110	31.392	31.654
30.100	29.344	29.736	30.104	30.445	30.761	31.055
29.100	28.615	29.042	29.440	29.811	30.157	30.490
27.744	27.031	28.386	28.811	29.208	29.570	29.927

## 10. Water temperature at every grid point

35.000	35.000	35.000	35.000	35.000	35.000	35.000
33.401	33.652	33.793	33.920	34.033	34.134	34.225
32.102	32.400	32.713	32.944	33.117	33.330	33.494
31.713	31.385	31.721	32.027	32.374	32.555	32.783
30.339	30.337	30.794	31.165	31.504	31.912	32.093
29.458	29.165	29.330	30.355	30.744	31.100	31.427
28.057	28.613	29.123	29.592	30.023	30.420	30.784
27.278	27.822	28.359	28.873	29.339	29.769	30.160
26.152	27.086	27.652	28.196	28.690	29.147	29.572

## 15. Water temperature at every grid point

35.000	35.000	35.000	35.000	35.000	35.000	35.000
33.501	33.637	33.737	33.922	34.034	34.135	34.225
32.200	32.480	32.727	32.950	33.151	33.337	33.495
31.733	31.400	31.734	32.036	32.311	32.560	32.786
30.464	30.407	30.810	31.179	31.513	31.819	32.098
29.377	29.489	29.943	30.370	30.750	31.109	31.433
28.089	28.639	29.145	29.610	30.037	30.431	30.793
27.262	27.831	28.323	28.843	29.355	29.762	30.176
26.493	27.137	27.688	28.217	28.708	29.162	29.583

## 20. Water temperature at every grid point

35.000	35.000	35.000	35.000	35.000	35.000	35.000
33.510	33.601	33.602	33.925	34.037	34.137	34.226
32.224	32.492	32.727	32.957	33.156	33.336	33.496
31.054	31.418	31.748	32.047	32.313	32.566	32.790
29.990	30.428	30.827	31.141	31.523	31.827	32.104
29.010	29.514	29.959	30.385	30.769	31.110	31.441
28.122	28.667	29.167	29.628	30.052	30.442	30.802
27.297	27.880	28.418	28.914	29.372	29.795	30.197
26.536	27.148	27.715	28.240	28.726	29.177	29.596

## 25. Water temperature at every grid point

35.000	35.000	35.000	35.000	35.000	35.000	35.000
33.511	33.611	33.604	33.930	34.040	34.136	34.227
32.225	32.505	32.747	32.965	33.162	33.340	33.501
31.070	31.435	31.751	32.058	32.327	32.572	32.794
30.010	30.440	30.841	31.205	31.534	31.835	32.109
29.041	29.538	29.949	30.402	30.781	31.120	31.448
28.153	28.691	29.190	29.647	30.067	30.454	30.811
27.323	27.910	28.443	28.935	29.384	29.800	30.198
26.573	27.150	27.747	28.262	28.745	29.193	29.608

26. Water temperature at every grid point = 0.6025E+01  
 27. Water temperature at every grid point = 0.7334E+01  
 28. Water temperature at every grid point = 0.5811E+03  
 29. Water temperature at every grid point = 0.1102E+01  
 30. Water temperature at every grid point = 0.1537E+07  
 31. Water temperature at every grid point = 0.4422E+07  
 32. Water temperature at every grid point = 0.7831E+07  
 33. Water temperature at every grid point = 0.7270E+07



Effect of Leaks under v/s exit water t  
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	TH	AL	LV	TH	AV	TA
33.0	33.0	64	30000.0	48720.1	97.50	27.10
33.0	33.0	64	30000.0	48720.1	90.51	28.83
33.0	33.0	64	70000.0	48720.1	92.08	29.77
36.0	36.0	61	30000.0	48720.1	93.17	28.04
36.0	36.0	61	30000.0	48720.1	97.62	30.25
36.0	36.0	61	70000.0	48720.1	100.01	31.52
33.0	33.0	64	30000.0	48720.1	92.01	26.07
33.0	33.0	64	30000.0	48720.1	90.09	28.08
33.0	33.0	64	70000.0	48720.1	97.90	29.20
36.0	36.0	61	30000.0	48720.1	98.21	26.99
36.0	36.0	61	30000.0	48720.1	93.12	29.51
36.0	36.0	61	70000.0	48720.1	95.76	30.95
38.0	38.0	64	30000.0	47927.1	112.25	31.40
38.0	38.0	64	30000.0	47927.1	110.42	33.17
38.0	38.0	64	70000.0	47927.1	118.00	34.20
41.0	41.0	64	30000.0	47927.1	118.07	32.12
41.0	41.0	64	30000.0	47927.1	124.76	34.36
41.0	41.0	64	70000.0	47927.1	128.18	35.73
38.0	38.0	64	30000.0	47927.1	110.93	30.23
38.0	38.0	64	30000.0	47927.1	110.72	32.30
38.0	38.0	64	70000.0	47927.1	113.31	33.53
41.0	41.0	64	30000.0	47927.1	112.25	30.03
41.0	41.0	64	30000.0	47927.1	118.96	33.51
41.0	41.0	64	70000.0	47927.1	122.72	35.08
43.0	43.0	64	30000.0	47157.6	142.73	35.77
43.0	43.0	64	30000.0	47157.6	148.44	37.45
43.0	43.0	64	70000.0	47157.6	151.68	38.55
46.0	46.0	64	30000.0	47157.6	149.87	36.23
46.0	46.0	64	30000.0	47157.6	158.10	38.40
46.0	46.0	64	70000.0	47157.6	162.92	39.85
43.0	43.0	64	30000.0	47157.6	134.45	34.39
43.0	43.0	64	30000.0	47157.6	141.00	36.45
43.0	43.0	64	70000.0	47157.6	144.72	37.76
46.0	46.0	64	30000.0	47157.6	141.50	34.89
46.0	46.0	64	30000.0	47157.6	150.53	37.42
46.0	46.0	64	70000.0	47157.6	155.83	39.08
48.0	48.0	64	30000.0	45411.6	180.55	40.14
48.0	48.0	64	30000.0	45411.6	188.20	41.70
48.0	48.0	64	70000.0	45411.6	192.78	42.82
51.0	51.0	64	30000.0	45411.6	188.36	40.43
51.0	51.0	64	30000.0	45411.6	199.22	42.41
51.0	51.0	64	70000.0	45411.6	205.96	43.87
48.0	48.0	64	30000.0	45411.6	169.60	38.61
48.0	48.0	64	30000.0	45411.6	178.36	40.55
48.0	48.0	64	70000.0	45411.6	183.61	41.91
51.0	51.0	64	30000.0	45411.6	177.31	38.03
51.0	51.0	64	30000.0	45411.6	189.24	41.29
51.0	51.0	64	70000.0	45411.6	190.62	42.98



[illegible]

12	13	14	15	16	17	18
21	33	34	35	36	37	38
22	33	34	35	36	37	38
23	33	34	35	36	37	38
24	36	37	38	39	40	41
25	36	37	38	39	40	41
26	36	37	38	39	40	41
27	33	34	35	36	37	38
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38	33	34	35	36	37	38
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43	33	34	35	36	37	38
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84	33	34	35	36	37	38
85	33	34	35	36	37	38
86	33	34	35	36	37	38
87	33	34	35	36	37	38
88	33	34	35	36	37	38
89	33	34	35	36	37	38
90	33	34	35	36	37	38
91	33	34	35	36	37	38
92	33	34	35	36	37	38
93	33	34	35	36	37	38
94	33	34	35	36	37	38
95	33	34	35	36	37	38

Load loss coefficients in case of counter  
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T <sub>1</sub>	Pressure	DT	PLA	MA/AV	NIH
20.	16.0	.000	30000.0	1.80	0.518
25.	16.0	.000	30000.0	1.00	0.409
25.	16.0	.000	30000.0	1.20	0.352
25.	16.0	.000	30000.0	1.40	0.322
25.	16.0	.000	30000.0	1.60	0.304
25.	16.0	.000	30000.0	1.80	0.291
30.	21.0	.000	30000.0	1.80	0.354
30.	21.0	.000	30000.0	1.00	0.282
30.	21.0	.000	30000.0	1.20	0.261
30.	21.0	.000	30000.0	1.40	0.245
30.	21.0	.000	30000.0	1.60	0.234
30.	21.0	.000	30000.0	1.80	0.227
35.	26.0	.000	30000.0	1.80	0.242
35.	26.0	.000	30000.0	1.00	0.210
35.	26.0	.000	30000.0	1.20	0.196
35.	26.0	.000	30000.0	1.40	0.187
35.	26.0	.000	30000.0	1.60	0.181
35.	26.0	.000	30000.0	1.80	0.177
40.	31.0	.000	30000.0	1.80	0.173
40.	31.0	.000	30000.0	1.00	0.156
40.	31.0	.000	30000.0	1.20	0.148
40.	31.0	.000	30000.0	1.40	0.143
40.	31.0	.000	30000.0	1.60	0.140
40.	31.0	.000	30000.0	1.80	0.137
45.	36.0	.000	30000.0	1.80	0.127
45.	36.0	.000	30000.0	1.00	0.117
45.	36.0	.000	30000.0	1.20	0.113
45.	36.0	.000	30000.0	1.40	0.110
45.	36.0	.000	30000.0	1.60	0.108
45.	36.0	.000	30000.0	1.80	0.106
50.	41.0	.000	30000.0	1.80	0.095
50.	41.0	.000	30000.0	1.00	0.088
50.	41.0	.000	30000.0	1.20	0.086
50.	41.0	.000	30000.0	1.40	0.084
50.	41.0	.000	30000.0	1.60	0.083
50.	41.0	.000	30000.0	1.80	0.082

Table 4.0.0 Lower coefficients in case of counter el  
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T1	T2	T3	RESIST	UT	PIV	V <sub>A/V</sub>	V <sub>IN</sub>	TJ
20.	5.	25.	16.0	.000	70000.0	1.00	0.570	3.
20.	5.	25.	16.0	.000	70000.0	1.00	0.400	1.
20.	5.	25.	16.0	.000	70000.0	1.20	0.352	1.
20.	5.	25.	16.0	.000	70000.0	1.40	0.322	0.
20.	5.	25.	16.0	.000	70000.0	1.60	0.304	0.
20.	5.	25.	16.0	.000	70000.0	1.80	0.291	0.
25.	10.	30.	21.0	.000	70000.0	1.00	0.354	1.
25.	10.	30.	21.0	.000	70000.0	1.00	0.288	1.
25.	10.	30.	21.0	.000	70000.0	1.20	0.261	0.
25.	10.	30.	21.0	.000	70000.0	1.40	0.245	0.
25.	10.	30.	21.0	.000	70000.0	1.60	0.234	0.
25.	10.	30.	21.0	.000	70000.0	1.80	0.227	0.
30.	15.	35.	26.0	.000	70000.0	1.00	0.242	1.
30.	15.	35.	26.0	.000	70000.0	1.00	0.210	0.
30.	15.	35.	26.0	.000	70000.0	1.20	0.196	0.
30.	15.	35.	26.0	.000	70000.0	1.40	0.187	0.
30.	15.	35.	26.0	.000	70000.0	1.60	0.181	0.
30.	15.	35.	26.0	.000	70000.0	1.80	0.177	0.
35.	20.	40.	31.0	.000	70000.0	1.00	0.173	0.
35.	20.	40.	31.0	.000	70000.0	1.00	0.156	0.
35.	20.	40.	31.0	.000	70000.0	1.20	0.148	0.
35.	20.	40.	31.0	.000	70000.0	1.40	0.143	0.
35.	20.	40.	31.0	.000	70000.0	1.60	0.140	0.
35.	20.	40.	31.0	.000	70000.0	1.80	0.137	0.
40.	25.	45.	36.0	.000	70000.0	1.00	0.127	0.
40.	25.	45.	36.0	.000	70000.0	1.00	0.117	0.
40.	25.	45.	36.0	.000	70000.0	1.20	0.113	0.
40.	25.	45.	36.0	.000	70000.0	1.40	0.110	0.
40.	25.	45.	36.0	.000	70000.0	1.60	0.108	0.
40.	25.	45.	36.0	.000	70000.0	1.80	0.106	0.
45.	30.	50.	41.0	.000	70000.0	1.00	0.095	0.
45.	30.	50.	41.0	.000	70000.0	1.00	0.088	0.
45.	30.	50.	41.0	.000	70000.0	1.20	0.086	0.
45.	30.	50.	41.0	.000	70000.0	1.40	0.084	0.
45.	30.	50.	41.0	.000	70000.0	1.60	0.083	0.
45.	30.	50.	41.0	.000	70000.0	1.80	0.082	0.

TABLE 2.0.0.1 COEFFICIENTS IN CASE OF COUNTER FLOW TOWER  
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F1	F2	F3	F4	DT	F1V	VA/V1	F1H	TJCH
30000.0	10000.0	30000.0	10000.0	1.0000	30000.0	1.000	-2.454	-13.135
30000.0	10000.0	30000.0	10000.0	1.0000	30000.0	1.000	-1.742	-5.465
30000.0	10000.0	30000.0	10000.0	1.0000	30000.0	1.000	3.200	11.452
30000.0	10000.0	30000.0	10000.0	1.0000	30000.0	1.000	1.616	4.967
30000.0	10000.0	30000.0	10000.0	1.0000	30000.0	1.000	1.740	3.338
30000.0	10000.0	30000.0	10000.0	1.0000	30000.0	1.000	1.003	2.040
30000.0	10000.0	30000.0	10000.0	1.0000	30000.0	1.000	-2.555	-11.424
30000.0	10000.0	30000.0	10000.0	1.0000	30000.0	1.000	0.541	10.997
30000.0	10000.0	30000.0	10000.0	1.0000	30000.0	1.000	1.242	3.190
30000.0	10000.0	30000.0	10000.0	1.0000	30000.0	1.000	0.955	2.964
30000.0	10000.0	30000.0	10000.0	1.0000	30000.0	1.000	0.823	2.236
30000.0	10000.0	30000.0	10000.0	1.0000	30000.0	1.000	0.746	1.804
30000.0	10000.0	30000.0	10000.0	1.0000	30000.0	1.000	2.576	14.022
30000.0	10000.0	30000.0	10000.0	1.0000	30000.0	1.000	0.982	4.295
30000.0	10000.0	30000.0	10000.0	1.0000	30000.0	1.000	0.740	2.701
30000.0	10000.0	30000.0	10000.0	1.0000	30000.0	1.000	0.637	1.942
30000.0	10000.0	30000.0	10000.0	1.0000	30000.0	1.000	0.578	1.584
30000.0	10000.0	30000.0	10000.0	1.0000	30000.0	1.000	0.541	1.317
30000.0	10000.0	30000.0	10000.0	1.0000	30000.0	1.000	0.842	4.628
30000.0	10000.0	30000.0	10000.0	1.0000	30000.0	1.000	0.581	2.566
30000.0	10000.0	30000.0	10000.0	1.0000	30000.0	1.000	0.494	1.818
30000.0	10000.0	30000.0	10000.0	1.0000	30000.0	1.000	0.448	1.414
30000.0	10000.0	30000.0	10000.0	1.0000	30000.0	1.000	0.410	1.157
30000.0	10000.0	30000.0	10000.0	1.0000	30000.0	1.000	0.400	0.981
30000.0	10000.0	30000.0	10000.0	1.0000	30000.0	1.000	0.487	2.704
30000.0	10000.0	30000.0	10000.0	1.0000	30000.0	1.000	0.386	1.717
30000.0	10000.0	30000.0	10000.0	1.0000	30000.0	1.000	0.347	1.287
30000.0	10000.0	30000.0	10000.0	1.0000	30000.0	1.000	0.324	1.031
30000.0	10000.0	30000.0	10000.0	1.0000	30000.0	1.000	0.309	0.861
30000.0	10000.0	30000.0	10000.0	1.0000	30000.0	1.000	0.290	0.739
30000.0	10000.0	30000.0	10000.0	1.0000	30000.0	1.000	0.320	1.794
30000.0	10000.0	30000.0	10000.0	1.0000	30000.0	1.000	0.270	1.210
30000.0	10000.0	30000.0	10000.0	1.0000	30000.0	1.000	0.251	0.937
30000.0	10000.0	30000.0	10000.0	1.0000	30000.0	1.000	0.239	0.765
30000.0	10000.0	30000.0	10000.0	1.0000	30000.0	1.000	0.231	0.547
30000.0	10000.0	30000.0	10000.0	1.0000	30000.0	1.000	0.225	0.560

NTU 4.0.0 lower coefficients in case of count  
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T2	T3	DESVAV	DT	TW	MA/MW	NTU
5.	25.	10.0	1.000	70000.0	1.80	-2.454
5.	25.	10.0	1.000	70000.0	1.00	-1.292
5.	25.	10.0	1.000	70000.0	1.20	3.200
5.	25.	10.0	1.000	70000.0	1.40	1.616
5.	25.	10.0	1.000	70000.0	1.50	1.240
5.	25.	10.0	1.000	70000.0	1.80	1.063
10.	30.	15.0	1.000	70000.0	1.80	-2.555
10.	30.	15.0	1.000	70000.0	1.00	2.541
10.	30.	15.0	1.000	70000.0	1.20	1.242
10.	30.	15.0	1.000	70000.0	1.40	0.955
10.	30.	15.0	1.000	70000.0	1.60	0.823
10.	30.	15.0	1.000	70000.0	1.80	0.746
15.	35.	20.0	1.000	70000.0	1.80	2.576
15.	35.	20.0	1.000	70000.0	1.00	0.982
15.	35.	20.0	1.000	70000.0	1.20	0.740
15.	35.	20.0	1.000	70000.0	1.40	0.637
15.	35.	20.0	1.000	70000.0	1.60	0.578
15.	35.	20.0	1.000	70000.0	1.80	0.541
20.	40.	25.0	1.000	70000.0	1.80	0.842
20.	40.	25.0	1.000	70000.0	1.00	0.581
20.	40.	25.0	1.000	70000.0	1.20	0.494
20.	40.	25.0	1.000	70000.0	1.40	0.448
20.	40.	25.0	1.000	70000.0	1.60	0.419
20.	40.	25.0	1.000	70000.0	1.80	0.400
25.	45.	30.0	1.000	70000.0	1.80	0.487
25.	45.	30.0	1.000	70000.0	1.00	0.386
25.	45.	30.0	1.000	70000.0	1.20	0.347
25.	45.	30.0	1.000	70000.0	1.40	0.324
25.	45.	30.0	1.000	70000.0	1.60	0.309
25.	45.	30.0	1.000	70000.0	1.80	0.299
30.	50.	35.0	1.000	70000.0	1.80	0.320
30.	50.	35.0	1.000	70000.0	1.00	0.270
30.	50.	35.0	1.000	70000.0	1.20	0.251
30.	50.	35.0	1.000	70000.0	1.40	0.239
30.	50.	35.0	1.000	70000.0	1.60	0.231
30.	50.	35.0	1.000	70000.0	1.80	0.225

7. Over coefficient calculation details  
 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199 200 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232 233 234 235 236 237 238 239 240 241 242 243 244 245 246 247 248 249 250 251 252 253 254 255 256 257 258 259 260 261 262 263 264 265 266 267 268 269 270 271 272 273 274 275 276 277 278 279 280 281 282 283 284 285 286 287 288 289 290 291 292 293 294 295 296 297 298 299 300 301 302 303 304 305 306 307 308 309 310 311 312 313 314 315 316 317 318 319 320 321 322 323 324 325 326 327 328 329 330 331 332 333 334 335 336 337 338 339 340 341 342 343 344 345 346 347 348 349 350 351 352 353 354 355 356 357 358 359 360 361 362 363 364 365 366 367 368 369 370 371 372 373 374 375 376 377 378 379 380 381 382 383 384 385 386 387 388 389 390 391 392 393 394 395 396 397 398 399 400 401 402 403 404 405 406 407 408 409 410 411 412 413 414 415 416 417 418 419 420 421 422 423 424 425 426 427 428 429 430 431 432 433 434 435 436 437 438 439 440 441 442 443 444 445 446 447 448 449 450 451 452 453 454 455 456 457 458 459 460 461 462 463 464 465 466 467 468 469 470 471 472 473 474 475 476 477 478 479 480 481 482 483 484 485 486 487 488 489 490 491 492 493 494 495 496 497 498 499 500 501 502 503 504 505 506 507 508 509 510 511 512 513 514 515 516 517 518 519 520 521 522 523 524 525 526 527 528 529 530 531 532 533 534 535 536 537 538 539 540 541 542 543 544 545 546 547 548 549 550 551 552 553 554 555 556 557 558 559 560 561 562 563 564 565 566 567 568 569 570 571 572 573 574 575 576 577 578 579 580 581 582 583 584 585 586 587 588 589 590 591 592 593 594 595 596 597 598 599 600 601 602 603 604 605 606 607 608 609 610 611 612 613 614 615 616 617 618 619 620 621 622 623 624 625 626 627 628 629 630 631 632 633 634 635 636 637 638 639 640 641 642 643 644 645 646 647 648 649 650 651 652 653 654 655 656 657 658 659 660 661 662 663 664 665 666 667 668 669 670 671 672 673 674 675 676 677 678 679 680 681 682 683 684 685 686 687 688 689 690 691 692 693 694 695 696 697 698 699 700 701 702 703 704 705 706 707 708 709 710 711 712 713 714 715 716 717 718 719 720 721 722 723 724 725 726 727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750 751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768 769 770 771 772 773 774 775 776 777 778 779 780 781 782 783 784 785 786 787 788 789 790 791 792 793 794 795 796 797 798 799 800 801 802 803 804 805 806 807 808 809 810 811 812 813 814 815 816 817 818 819 820 821 822 823 824 825 826 827 828 829 830 831 832 833 834 835 836 837 838 839 840 841 842 843 844 845 846 847 848 849 850 851 852 853 854 855 856 857 858 859 860 861 862 863 864 865 866 867 868 869 870 871 872 873 874 875 876 877 878 879 880 881 882 883 884 885 886 887 888 889 890 891 892 893 894 895 896 897 898 899 900 901 902 903 904 905 906 907 908 909 910 911 912 913 914 915 916 917 918 919 920 921 922 923 924 925 926 927 928 929 930 931 932 933 934 935 936 937 938 939 940 941 942 943 944 945 946 947 948 949 950 951 952 953 954 955 956 957 958 959 960 961 962 963 964 965 966 967 968 969 970 971 972 973 974 975 976 977 978 979 980 981 982 983 984 985 986 987 988 989 990 991 992 993 994 995 996 997 998 999 1000 1001 1002 1003 1004 1005 1006 1007 1008 1009 1010 1011 1012 1013 1014 1015 1016 1017 1018 1019 1020 1021 1022 1023 1024 1025 1026 1027 1028 1029 1030 1031 1032 1033 1034 1035 1036 1037 1038

[illegible]

		T1	T2	T3	DISIAY	D1	VFLUCTIV	TAW
		35 0 0	30 0 00	50 00000	41 00000	0.6000000	2 500000	30000.00
		ATK A	ATK A	LT DIFF	FRAC EN DIFF	MEAN IF FRAC	NTU	SUM NEW
		INCH	INCH	(IS=1)				INCH
17 100	1 00	174 174	49 839	76 137	0 01313	0' 01297	0.0078	0.0078
0 330	1 00	1 0 337	102 197	78 140	0 01280	0' 01263	0 0076	0 0154
0 350	1 00	1 0 362	115 558	80 304	0 01245	0' 01228	0 0074	0.0227
0 1275	1 00	01 053	109 720	82 633	0 01210	0' 01192	0 0072	0 0299
0 107	2 00	107 318	112 262	85 123	0 01175	0 01157	0 0069	0 0368
0 2065	2 00	115 648	87 811	0 01139	0 01121	0.0067	0.0435	0.0377

0.2361	0.000	15.000	222.704	125.751	95.574	0.01031	0.01013	0.0051	0.0624	0.0342
0.2361	0.000	15.000	224.519	129.122	100.427	0.00990	0.00978	0.0059	0.0683	0.0330
0.3071	0.000	17.000	230.527	132.135	104.071	0.00961	0.00943	0.0057	0.0740	0.0319
0.4151	0.000	17.500	243.540	135.970	107.975	0.00920	0.00909	0.0055	0.0794	0.0307
0.4451	0.000	20.000	251.335	137.219	112.027	0.00892	0.00876	0.0053	0.0847	0.0296
0.4753	0.000	20.500	259.062	142.627	110.435	0.00859	0.00843	0.0051	0.0897	0.0285
0.5130	0.000	20.400	267.037	146.009	121.028	0.00826	0.00810	0.0049	0.0946	0.0274
0.5315	0.000	22.000	275.269	149.394	125.875	0.00794				

TABLE 4.8 Detail of variation of tower coefficient in every grid point

VOLUME OF TOWER USED = 7.767 m<sup>3</sup>s  
 NUMBER OF CTRDS USED = 6 A R

ENTER CONDITIONS :  
 dry bulb temperature of air = 30.00 C  
 wet bulb temperature of air = 15.00 C  
 water temperature on to the tower = 35.00 C  
 mass of water fed to the tower = 50000.0 kg/hr  
 mass of air blown = 38976.1 kg/hr  
 enthalpy of entering air = 41.28 KJ  
 humidity of entering air = 0.04508 kg/kg of dry air

SUM T <sub>DB</sub> = 0.016	0.036	0.055	0.074	0.093	0.112	0.131	0.150
SUM T <sub>WB</sub> = 0.107	0.210	0.312	0.415	0.517	0.620	0.722	0.825
SUM T <sub>DB</sub> = 0.012	0.038	0.057	0.076	0.095	0.114	0.132	0.151
SUM T <sub>WB</sub> = 0.103	0.205	0.308	0.411	0.513	0.615	0.718	0.820
SUM T <sub>DB</sub> = 0.013	0.036	0.057	0.076	0.095	0.114	0.132	0.151
SUM T <sub>WB</sub> = 0.103	0.205	0.308	0.411	0.513	0.615	0.718	0.821
SUM T <sub>DB</sub> = 0.010	0.038	0.058	0.076	0.095	0.114	0.133	0.151
SUM T <sub>WB</sub> = 0.102	0.206	0.309	0.411	0.513	0.615	0.718	0.821
SUM T <sub>DB</sub> = 0.012	0.039	0.058	0.077	0.095	0.114	0.133	0.152
SUM T <sub>WB</sub> = 0.102	0.206	0.309	0.411	0.514	0.615	0.719	0.821
SUM T <sub>DB</sub> = 0.012	0.039	0.058	0.077	0.096	0.114	0.133	0.152
SUM T <sub>WB</sub> = 0.103	0.206	0.309	0.412	0.514	0.617	0.719	0.822
SUM T <sub>DB</sub> = 0.012	0.039	0.058	0.077	0.096	0.115	0.133	0.152
SUM T <sub>WB</sub> = 0.103	0.206	0.309	0.412	0.515	0.618	0.720	0.823
SUM T <sub>DB</sub> = 0.002	0.019	0.028	0.037	0.046	0.055	0.065	0.074
SUM T <sub>WB</sub> = 0.026	0.052	0.077	0.103	0.129	0.154	0.180	0.206

ENTER CONDITIONS :  
 Average temperature of leaving water = 27.96 C  
 Average enthalpy of leaving air = 80.81 KJ  
 humidity of leaving air = 0.019418 kg/kg of dry air

RESULTS :  
 mass of water evaporated = 581.1 kg/hr  
 heat released = 1540869.4 KJ/hr  
 number of fill required = 292  
 volume of tower based on evaporation rate = 6.8250 m<sup>3</sup>s



TABLE 4.0 Comparison of volume of tower based  
on tower dimensions and humidity

T <sub>1</sub>	T <sub>2</sub>	T <sub>3</sub>	T <sub>AV</sub>	V	T <sub>AV</sub>	VOLUME BASED ON	
						DTM	HUMID
31.1	15.0	35.0	30000.0	2.5	19.97	7.787	6.844
30.1	15.0	35.0	50000.0	1.5	21.35	7.787	6.840
33.1	15.0	35.0	50000.0	2.0	21.95	7.787	6.825
30.1	15.1	35.0	50000.0	2.5	21.97	7.787	6.820
31.0	15.0	35.0	70000.0	1.5	28.94	7.787	6.863
30.1	15.1	35.0	70000.0	2.0	28.95	7.787	6.832
30.1	15.5	35.0	70000.0	2.5	28.94	7.787	6.824
41.1	25.0	45.0	30000.0	2.0	29.95	7.787	6.835
40.1	25.0	45.0	30000.0	2.5	29.95	7.787	6.829
40.0	25.0	45.0	50000.0	1.5	31.97	7.787	6.822
40.0	25.1	45.0	50000.0	2.0	31.99	7.787	6.818
40.1	25.1	45.0	50000.0	2.5	31.94	7.787	6.816
40.0	25.1	45.0	70000.0	1.5	38.95	7.787	6.826
40.0	25.0	45.0	70000.0	2.0	38.97	7.787	6.820
40.1	25.1	45.0	70000.0	2.5	38.98	7.787	6.817

TABLE 1.10 Heat rejection and % Rate of evaporation  
in case of cross flow

T1	T2	T3	T <sub>FW</sub>	T <sub>MA</sub>	T <sub>AV</sub>	Q	EVAP
30.0	24.0	33.0	30000.0	48720.1	27.38	.7380E+06	1.95
30.0	24.0	33.0	50000.0	48720.1	29.01	.8737E+06	1.65
30.0	24.0	33.0	70000.0	48720.1	29.92	.9443E+06	1.50
30.0	24.0	35.0	30000.0	48720.1	28.32	.1007E+07	2.23
30.0	24.0	35.0	50000.0	48720.1	30.48	.1209E+07	1.87
30.0	24.0	35.0	70000.0	48720.1	31.71	.1316E+07	1.67
30.0	24.0	33.0	30000.0	48720.1	25.34	.6730E+06	2.14
30.0	24.0	33.0	50000.0	48720.1	28.30	.1030E+07	1.78
30.0	24.0	33.0	70000.0	48720.1	29.38	.1111E+07	1.59
30.0	24.0	30.0	30000.0	48720.1	27.31	.1139E+07	2.42
30.0	24.0	30.0	50000.0	48720.1	29.78	.1301E+07	1.99
30.0	24.0	30.0	70000.0	48720.1	31.18	.1480E+07	1.70
35.0	29.0	35.0	30000.0	47927.1	31.68	.8352E+06	2.08
35.0	29.0	35.0	50000.0	47927.1	33.37	.1021E+07	1.77
35.0	29.0	35.0	70000.0	47927.1	34.37	.1121E+07	1.60
35.0	29.0	41.0	30000.0	47927.1	32.40	.1135E+07	2.41
35.0	29.0	41.0	50000.0	47927.1	34.62	.1407E+07	2.02
35.0	29.0	41.0	70000.0	47927.1	35.46	.1558E+07	1.80
35.0	27.0	38.0	30000.0	47927.1	30.51	.9891E+06	2.30
35.0	27.0	38.0	50000.0	47927.1	32.51	.1202E+07	1.92
35.0	27.0	38.0	70000.0	47927.1	33.73	.1318E+07	1.71
35.0	27.0	41.0	30000.0	47927.1	31.46	.1285E+07	2.62
35.0	27.0	41.0	50000.0	47927.1	33.81	.1584E+07	2.17
35.0	27.0	41.0	70000.0	47927.1	35.34	.1751E+07	1.91
40.0	34.0	43.0	30000.0	47157.5	35.99	.9339E+06	2.22
40.0	34.0	43.0	50000.0	47157.5	37.67	.1184E+07	1.90
40.0	34.0	43.0	70000.0	47157.5	38.74	.1325E+07	1.71
40.0	32.0	40.0	30000.0	47157.5	36.50	.1264E+07	2.59
40.0	32.0	40.0	50000.0	47157.5	38.68	.1626E+07	2.20
40.0	32.0	40.0	70000.0	47157.5	40.10	.1836E+07	1.95
40.0	32.0	43.0	30000.0	47157.5	34.67	.1108E+07	2.47
40.0	32.0	43.0	50000.0	47157.5	36.71	.1395E+07	2.07
40.0	32.0	43.0	70000.0	47157.5	37.99	.1557E+07	1.84
40.0	32.0	40.0	30000.0	47157.5	35.21	.1434E+07	2.83
40.0	32.0	40.0	50000.0	47157.5	37.75	.1832E+07	2.30
40.0	32.0	40.0	70000.0	47157.5	39.37	.2063E+07	2.08
45.0	39.0	48.0	30000.0	46411.5	40.34	.1028E+07	2.35
45.0	39.0	48.0	50000.0	46411.5	41.92	.1360E+07	2.04
45.0	39.0	48.0	70000.0	46411.5	43.04	.1556E+07	1.84
45.0	39.0	51.0	30000.0	46411.5	40.67	.1385E+07	2.70
45.0	39.0	51.0	50000.0	46411.5	42.69	.1858E+07	2.38
45.0	39.0	51.0	70000.0	46411.5	44.15	.2148E+07	2.13
45.0	37.0	48.0	30000.0	46411.5	38.87	.1225E+07	2.63
45.0	37.0	48.0	50000.0	46411.5	40.82	.1604E+07	2.23
45.0	37.0	48.0	70000.0	46411.5	42.16	.1829E+07	1.99
45.0	37.0	51.0	30000.0	46411.5	39.23	.1577E+07	3.03
45.0	37.0	51.0	50000.0	46411.5	41.62	.2096E+07	2.57
45.0	37.0	51.0	70000.0	46411.5	43.30	.2414E+07	2.28

TABLE 4.11 Various costs v/s flow rate

FWW	TMA	POWER	WATER	LAND	FOUL	TOTAL
20000	48720	66317	110043	1414	41000	103700
30000	48720	92886	174126	2553	44110	200071
50000	48720	77827	221230	1001	45104	200054
60000	48720	90043	257781	1281	45104	250160
70000	48720	97210	301477	1222	45890	400010
80000	48720	105930	347800	1470	46310	455280
20000	29232	25731	110290	2870	20000	144603
20000	38976	42545	117048	1005	35000	161128
20000	48720	66317	110043	1414	41000	184700
20000	58464	98041	117160	1173	53000	216389
20000	68208	142355	177100	1001	61000	260000
30000	48720	92886	174126	2553	44110	269371
30000	58464	135759	170245	2091	53410	314000
30000	68208	191416	174730	1727	61110	367683

[illegible]

一、《说文解字》：中国第一部系统分析汉字字形、考究字源的字典，由东汉许慎编著。

1. 100% POLYMER TYPE

MADE OF paper by Baker and Stryock

C- A COMPREHENSIVE APPROACH TO THE ANALYSIS OF COOLING TOWER PERFORMANCE

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DIMENSION S1(30,30), S2(30,30), S22(30,30), S3(30,30), DW(30,30)
DIMENSION DINV(30,30), HSE(30,30), WSE(30,30), ALFE(30,30)
DIMENSION VOLUME(30,30), VOLUB(30,30), DET(30,30), ENDFE(30,30)
DIMENSION FENAT(30,30), FADL(30,30), FRENDT(30,30), WSS(30,30)
DIMENSION FEMCAN(30,30), NTU(30,30), SUMATH(30,30), TJCH(30,30)
DIMENSION TUNFE(30,30), RANGE(30,30), WALEV(30)

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NAME, DOB, LENGTH, WEIGHT, LATITUDE, HEIGHT, MASS, SEX, SQUARE  
 COLOR, HEIGHT, WEIGHT, MODE, YEAR  
 INTEGER, STRING

functional sub-programs

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T(X)=1.004505E-2.0707E-5*X+9.115E-7+Y**2
T(X)=2.05564E-9.817E*P((7.21379+(1.152E-5-1.787E-9*(273.16+XJ))*
1/(A-210))*Z)))+(0.47.31/(273.16+X)-1))
T(X)=(1.8*A+32J)+459.57
T(X)=(A.210+0.3+3E-04+T(X)-0.297E-08*T(X)**2)*4.187
T(X)=4.2097187-1.1125E-03*X+1.375E-05*X**2
T(X)=(597.34-0.555*A-0.2309+10**((5.1453-1540/(X+273.16J)))*4.18
17
T(X)=(0.90615*A+(1.9239E-6)*X**2-0.13468*10**(-0.036*XJ+0.1346
16))+4.187
Q(X)=T(X)+H(X)
Q(X)=1.291-(1.525E-3*A)+1.125E-5*A**2
T(X)=0.0207+(6.5E-5*X)-(2.5E-7*X**2)
Y(X)=1.3245E-5+6.525E-8*X+1.545E-10*X**2
V(X)=0.333*ALOG10(A)**2+0.177046*ALOG10(A)+2.6949E-3
U(X)=1.2930/(0.27986+EXP(-0.09338*A))

```

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1PRT% (UNIT=20, FTYPE='DAT.CDR')
1PRT% (UNIT=01, FTYPE='CONST.ALB')
1PRT% (UNIT=21, FTYPE='E-JVM.FAC')
1PRT% (UNIT=22)
1PRT% (UNIT=40)
1PRT% (UNIT=05)
1PRT% (20,*) , M, N, LENGTH, WIDTH, LUGH, RP, DENWAT, C1, C2
1PRT% (20,*) , GRAY, AVDFAR, GASCON
1PRT% (20,*) , ABRANG
1PRT% (20,*) , STDF1, SIDE2
1PRT% (20,*) , PAFRFF, JF, PUMFF
1PRT% (20,*) , YEAR
1PRT% (20,*) , WALCUS, WDCFT
1PRT% (20,*) , GWAS, UNLVG
1PRT% (20,*) , VEGWAT, PIPERT
1PRT% (20,*) , DRIFT, RLDOWN
1PRT% (20,*) , LIFE, RATTNT
1PRT% (20,*) , IF RATTNT IS 1---TRIANGULAR SLATS.

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ARRANG-1f ARRANG IS 1---TRIANGULAR SLATS  
2---RECTANGULAR SLATS

TE LAROMANG .HQ. 1) 67 TJ 67  
TE LAROMANG .FO. 2) 67 TJ 68

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P1=10; P2=0.028;
P1=(SIDE1+SIDE2+SQRT(SIDE1**2+SIDE2**2))
AREA=(SIDE1*SIDE2)/2

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A1=12.9; A2=0.012
FDE1=(S1DE1+S1DE2)*Z
AOFDE=S1DE1*S1DE2

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F1FAR=YEAR/4
1FAR=FYFAR
IF(ABS(FYEAR-JYEAR).EQ.0.0) GJ 17 22
HYEAR=365*24
GJ 10 23
HYEAR=365*24
CF1FIE=0.3049
CFKID=0.45359
CFJUD=JUDCF*1.4/CF1FIE*3

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T1=(T3-13.43) GO TO 30
T2=T1-15
T3=T1+5
DESTAV=13-15
IF (T3-13.43) GO TO 30
PRINT 51, T1, T2, T3

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T1-TEMPERATURE OF AIR (DRY BULB TEMPERATURE -TDB IN DEGREE C)
T2-TEMPERATURE OF AIR (WET BULB TEMPERATURE - TWB IN DEGREE C)
T3-TEMPERATURE OF HOT WATER (IN DEGREE C)
DESTAV-Desire Temperature Of Outlet Water (in Degree C)
TAV-Average temperature of water leaving the tower in C
V-velocity of air in m/sec
V1M - Velocity of air in m/min
ALPHA-HEAT TRANSFER COEFFICIENT
PR-PRANDTL NUMBER
K - Thermal conductivity of air in kcal/m-hr-C
VISC - Kinematic viscosity in m**2/sec
rhoA-mass of air in kg/m3
rhoW-mass of water in kg/m3
CPACU -Conversion Factor from Pound to Kg and vice versa
CPWFT-Conversion factor from water to Feet and vice versa
rhoWAF-Density of water in kg/m**3 i.e., 1000
rhoA - Density of air in kg/m**3
alpha - Coefficient which is a function of temperature & Pressure
CPACU(=1.025)-Specific heat of dry air in KJ/c-Kg
hC-Heat transfer Coefficient in kcal/hr-m**2-C
hCW - Heat transfer Coefficient in KJ/hr-m**2 dry air/hr-m**2
P1 & P2 (Pressure)-in terms of m**2
N - Number Of Grid Divisions For Calculation Purpose
NACT-Actual number of grid points Available For Calculation
H - Height of fill material in m
DODIA-Equivalent diameter of fill material in m
AA-Area of Cross Section of fill material in m**2
T1-temperature of water at every grid point
T2-Humidity of air at every grid point
T3-Humidity of air at every grid point
Q1-Heat Absorbed by air from Hot Water In The Process of Cooling
Q2-Heat Given up from Hot Water to Air
N - Number of Fills Along The Height of Tower
N - Number of Fills Along The Height of Tower
N - Number of Fills per unit Area
N - Number of Fills along the Width of the tower
N - Number of Fills along the Height of the Tower
DISTH-Distance between each Fill(along height)
DISTW-Distance between each Fill(along width)
VSP-Superficial velocity
V1M - Specific volume of air
N - Number of transfer Units
N - Tower Characteristic
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P1=P1+P2+P3+P4+P5+P6+P7+P8+P9+P10+P11+P12+P13+P14+P15+P16+P17+P18+P19+P20+P21+P22+P23+P24+P25+P26+P27+P28+P29+P30+P31+P32+P33+P34+P35+P36+P37+P38+P39+P40+P41+P42+P43+P44+P45+P46+P47+P48+P49+P50+P51+P52+P53+P54+P55+P56+P57+P58+P59+P60+P61+P62+P63+P64+P65+P66+P67+P68+P69+P70+P71+P72+P73+P74+P75+P76+P77+P78+P79+P80+P81+P82+P83+P84+P85+P86+P87+P88+P89+P90+P91+P92+P93+P94+P95+P96+P97+P98+P99+P100+P101+P102+P103+P104+P105+P106+P107+P108+P109+P110+P111+P112+P113+P114+P115+P116+P117+P118+P119+P120+P121+P122+P123+P124+P125+P126+P127+P128+P129+P130+P131+P132+P133+P134+P135+P136+P137+P138+P139+P140+P141+P142+P143+P144+P145+P146+P147+P148+P149+P150+P151+P152+P153+P154+P155+P156+P157+P158+P159+P160+P161+P162+P163+P164+P165+P166+P167+P168+P169+P170+P171+P172+P173+P174+P175+P176+P177+P178+P179+P180+P181+P182+P183+P184+P185+P186+P187+P188+P189+P190+P191+P192+P193+P194+P195+P196+P197+P198+P199+P200+P201+P202+P203+P204+P205+P206+P207+P208+P209+P210+P211+P212+P213+P214+P215+P216+P217+P218+P219+P220+P221+P222+P223+P224+P225+P226+P227+P228+P229+P230+P231+P232+P233+P234+P235+P236+P237+P238+P239+P240+P241+P242+P243+P244+P245+P246+P247+P248+P249+P250+P251+P252+P253+P254+P255+P256+P257+P258+P259+P260+P261+P262+P263+P264+P265+P266+P267+P268+P269+P270+P271+P272+P273+P274+P275+P276+P277+P278+P279+P280+P281+P282+P283+P284+P285+P286+P287+P288+P289+P290+P291+P292+P293+P294+P295+P296+P297+P298+P299+P300+P301+P302+P303+P304+P305+P306+P307+P308+P309+P310+P311+P312+P313+P314+P315+P316+P317+P318+P319+P320+P321+P322+P323+P324+P325+P326+P327+P328+P329+P330+P331+P332+P333+P334+P335+P336+P337+P338+P339+P340+P341+P342+P343+P344+P345+P346+P347+P348+P349+P350+P351+P352+P353+P354+P355+P356+P357+P358+P359+P360+P361+P362+P363+P364+P365+P366+P367+P368+P369+P370+P371+P372+P373+P374+P375+P376+P377+P378+P379+P380+P381+P382+P383+P384+P385+P386+P387+P388+P389+P390+P391+P392+P393+P394+P395+P396+P397+P398+P399+P400+P401+P402+P403+P404+P405+P406+P407+P408+P409+P410+P411+P412+P413+P414+P415+P416+P417+P418+P419+P420+P421+P422+P423+P424+P425+P426+P427+P428+P429+P430+P431+P432+P433+P434+P435+P436+P437+P438+P439+P440+P441+P442+P443+P444+P445+P446+P447+P448+P449+P450+P451+P452+P453+P454+P455+P456+P457+P458+P459+P460+P461+P462+P463+P464+P465+P466+P467+P468+P469+P470+P471+P472+P473+P474+P475+P476+P477+P478+P479+P480+P481+P482+P483+P484+P485+P486+P487+P488+P489+P490+P491+P492+P493+P494+P495+P496+P497+P498+P499+P500+P501+P502+P503+P504+P505+P506+P507+P508+P509+P510+P511+P512+P513+P514+P515+P516+P517+P518+P519+P520+P521+P522+P523+P524+P525+P526+P527+P528+P529+P530+P531+P532+P533+P534+P535+P536+P537+P538+P539+P540+P541+P542+P543+P544+P545+P546+P547+P548+P549+P550+P551+P552+P553+P554+P555+P556+P557+P558+P559+P560+P561+P562+P563+P564+P565+P566+P567+P568+P569+P570+P571+P572+P573+P574+P575+P576+P577+P578+P579+P580+P581+P582+P583+P584+P585+P586+P587+P588+P589+P590+P591+P592+P593+P594+P595+P596+P597+P598+P599+P600+P601+P602+P603+P604+P605+P606+P607+P608+P609+P610+P611+P612+P613+P614+P615+P616+P617+P618+P619+P620+P621+P622+P623+P624+P625+P626+P627+P628+P629+P630+P631+P632+P633+P634+P635+P636+P637+P638+P639+P640+P641+P642+P643+P644+P645+P646+P647+P648+P649+P650+P651+P652+P653+P654+P655+P656+P657+P658+P659+P660+P661+P662+P663+P664+P665+P666+P667+P668+P669+P670+P671+P672+P673+P674+P675+P676+P677+P678+P679+P680+P681+P682+P683+P684+P685+P686+P687+P688+P689+P690+P691+P692+P693+P694+P695+P696+P697+P698+P699+P700+P701+P702+P703+P704+P705+P706+P707+P708+P709+P710+P711+P712+P713+P714+P715+P716+P717+P718+P719+P720+P721+P722+P723+P724+P725+P726+P727+P728+P729+P730+P731+P732+P733+P734+P735+P736+P737+P738+P739+P740+P741+P742+P743+P744+P745+P746+P747+P748+P749+P750+P751+P752+P753+P754+P755+P756+P757+P758+P759+P760+P761+P762+P763+P764+P765+P766+P767+P768+P769+P770+P771+P772+P773+P774+P775+P776+P777+P778+P779+P780+P781+P782+P783+P784+P785+P786+P787+P788+P789+P790+P791+P792+P793+P794+P795+P796+P797+P798+P799+P800+P801+P802+P803+P804+P805+P806+P807+P808+P809+P810+P811+P812+P813+P814+P815+P816+P817+P818+P819+P820+P821+P822+P823+P824+P825+P826+P827+P828+P829+P830+P831+P832+P833+P834+P835+P836+P837+P838+P839+P840+P841+P842+P843+P844+P845+P846+P847+P848+P849+P850+P851+P852+P853+P854+P855+P856+P857+P858+P859+P860+P861+P862+P863+P864+P865+P866+P867+P868+P869+P870+P871+P872+P873+P874+P875+P876+P877+P878+P879+P880+P881+P882+P883+P884+P885+P886+P887+P888+P889+P890+P891+P892+P893+P894+P895+P896+P897+P898+P899+P900+P901+P902+P903+P904+P905+P906+P907+P908+P909+P910+P911+P912+P913+P914+P915+P916+P917+P918+P919+P920+P921+P922+P923+P924+P925+P926+P927+P928+P929+P930+P931+P932+P933+P934+P935+P936+P937+P938+P939+P940+P941+P942+P943+P944+P945+P946+P947+P948+P949+P950+P951+P952+P953+P954+P955+P956+P957+P958+P959+P960+P961+P962+P963+P964+P965+P966+P967+P968+P969+P970+P971+P972+P973+P974+P975+P976+P977+P978+P979+P980+P981+P982+P983+P984+P985+P986+P987+P988+P989+P990+P991+P992+P993+P994+P995+P996+P997+P998+P999+1000

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=====
Calculation of Reynold's Number & Friction factor
=====
R1=P1/3.1415926
R2=P1/2

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1  A=2000*(1+1.14)*A*(2501.1+1.884*11)
2  Z=2000*(1+1.14)*Z*(2501.1+1.884*11)
3  V=2000*(1+1.14)*V*(2501.1+1.884*11)
4  W=2000*(1+1.14)*W*(2501.1+1.884*11)
5  C=2000*(1+1.14)*C*(2501.1+1.884*11)
6  D=2000*(1+1.14)*D*(2501.1+1.884*11)
7  E=2000*(1+1.14)*E*(2501.1+1.884*11)
8  F=2000*(1+1.14)*F*(2501.1+1.884*11)
9  G=2000*(1+1.14)*G*(2501.1+1.884*11)
10 H=2000*(1+1.14)*H*(2501.1+1.884*11)
11 I=2000*(1+1.14)*I*(2501.1+1.884*11)
12 J=2000*(1+1.14)*J*(2501.1+1.884*11)
13 K=2000*(1+1.14)*K*(2501.1+1.884*11)
14 L=2000*(1+1.14)*L*(2501.1+1.884*11)
15 M=2000*(1+1.14)*M*(2501.1+1.884*11)
16 N=2000*(1+1.14)*N*(2501.1+1.884*11)
17 O=2000*(1+1.14)*O*(2501.1+1.884*11)
18 P=2000*(1+1.14)*P*(2501.1+1.884*11)
19 Q=2000*(1+1.14)*Q*(2501.1+1.884*11)
20 R=2000*(1+1.14)*R*(2501.1+1.884*11)
21 S=2000*(1+1.14)*S*(2501.1+1.884*11)
22 T=2000*(1+1.14)*T*(2501.1+1.884*11)
23 U=2000*(1+1.14)*U*(2501.1+1.884*11)
24 V=2000*(1+1.14)*V*(2501.1+1.884*11)
25 W=2000*(1+1.14)*W*(2501.1+1.884*11)
26 X=2000*(1+1.14)*X*(2501.1+1.884*11)
27 Y=2000*(1+1.14)*Y*(2501.1+1.884*11)
28 Z=2000*(1+1.14)*Z*(2501.1+1.884*11)
29 A=2000*(1+1.14)*A*(2501.1+1.884*11)
30 B=2000*(1+1.14)*B*(2501.1+1.884*11)
31 C=2000*(1+1.14)*C*(2501.1+1.884*11)
32 D=2000*(1+1.14)*D*(2501.1+1.884*11)
33 E=2000*(1+1.14)*E*(2501.1+1.884*11)
34 F=2000*(1+1.14)*F*(2501.1+1.884*11)
35 G=2000*(1+1.14)*G*(2501.1+1.884*11)
36 H=2000*(1+1.14)*H*(2501.1+1.884*11)
37 I=2000*(1+1.14)*I*(2501.1+1.884*11)
38 J=2000*(1+1.14)*J*(2501.1+1.884*11)
39 K=2000*(1+1.14)*K*(2501.1+1.884*11)
40 L=2000*(1+1.14)*L*(2501.1+1.884*11)
41 M=2000*(1+1.14)*M*(2501.1+1.884*11)
42 N=2000*(1+1.14)*N*(2501.1+1.884*11)
43 O=2000*(1+1.14)*O*(2501.1+1.884*11)
44 P=2000*(1+1.14)*P*(2501.1+1.884*11)
45 Q=2000*(1+1.14)*Q*(2501.1+1.884*11)
46 R=2000*(1+1.14)*R*(2501.1+1.884*11)
47 S=2000*(1+1.14)*S*(2501.1+1.884*11)
48 T=2000*(1+1.14)*T*(2501.1+1.884*11)
49 U=2000*(1+1.14)*U*(2501.1+1.884*11)
50 V=2000*(1+1.14)*V*(2501.1+1.884*11)
51 W=2000*(1+1.14)*W*(2501.1+1.884*11)
52 X=2000*(1+1.14)*X*(2501.1+1.884*11)
53 Y=2000*(1+1.14)*Y*(2501.1+1.884*11)
54 Z=2000*(1+1.14)*Z*(2501.1+1.884*11)
55 A=2000*(1+1.14)*A*(2501.1+1.884*11)
56 B=2000*(1+1.14)*B*(2501.1+1.884*11)
57 C=2000*(1+1.14)*C*(2501.1+1.884*11)
58 D=2000*(1+1.14)*D*(2501.1+1.884*11)
59 E=2000*(1+1.14)*E*(2501.1+1.884*11)
60 F=2000*(1+1.14)*F*(2501.1+1.884*11)
61 G=2000*(1+1.14)*G*(2501.1+1.884*11)
62 H=2000*(1+1.14)*H*(2501.1+1.884*11)
63 I=2000*(1+1.14)*I*(2501.1+1.884*11)
64 J=2000*(1+1.14)*J*(2501.1+1.884*11)
65 K=2000*(1+1.14)*K*(2501.1+1.884*11)
66 L=2000*(1+1.14)*L*(2501.1+1.884*11)
67 M=2000*(1+1.14)*M*(2501.1+1.884*11)
68 N=2000*(1+1.14)*N*(2501.1+1.884*11)
69 O=2000*(1+1.14)*O*(2501.1+1.884*11)
70 P=2000*(1+1.14)*P*(2501.1+1.884*11)
71 Q=2000*(1+1.14)*Q*(2501.1+1.884*11)
72 R=2000*(1+1.14)*R*(2501.1+1.884*11)
73 S=2000*(1+1.14)*S*(2501.1+1.884*11)
74 T=2000*(1+1.14)*T*(2501.1+1.884*11)
75 U=2000*(1+1.14)*U*(2501.1+1.884*11)
76 V=2000*(1+1.14)*V*(2501.1+1.884*11)
77 W=2000*(1+1.14)*W*(2501.1+1.884*11)
78 X=2000*(1+1.14)*X*(2501.1+1.884*11)
79 Y=2000*(1+1.14)*Y*(2501.1+1.884*11)
80 Z=2000*(1+1.14)*Z*(2501.1+1.884*11)
81 A=2000*(1+1.14)*A*(2501.1+1.884*11)
82 B=2000*(1+1.14)*B*(2501.1+1.884*11)
83 C=2000*(1+1.14)*C*(2501.1+1.884*11)
84 D=2000*(1+1.14)*D*(2501.1+1.884*11)
85 E=2000*(1+1.14)*E*(2501.1+1.884*11)
86 F=2000*(1+1.14)*F*(2501.1+1.884*11)
87 G=2000*(1+1.14)*G*(2501.1+1.884*11)
88 H=2000*(1+1.14)*H*(2501.1+1.884*11)
89 I=2000*(1+1.14)*I*(2501.1+1.884*11)
90 J=2000*(1+1.14)*J*(2501.1+1.884*11)
91 K=2000*(1+1.14)*K*(2501.1+1.884*11)
92 L=2000*(1+1.14)*L*(2501.1+1.884*11)
93 M=2000*(1+1.14)*M*(2501.1+1.884*11)
94 N=2000*(1+1.14)*N*(2501.1+1.884*11)
95 O=2000*(1+1.14)*O*(2501.1+1.884*11)
96 P=2000*(1+1.14)*P*(2501.1+1.884*11)
97 Q=2000*(1+1.14)*Q*(2501.1+1.884*11)
98 R=2000*(1+1.14)*R*(2501.1+1.884*11)
99 S=2000*(1+1.14)*S*(2501.1+1.884*11)
100 T=2000*(1+1.14)*T*(2501.1+1.884*11)
101 U=2000*(1+1.14)*U*(2501.1+1.884*11)
102 V=2000*(1+1.14)*V*(2501.1+1.884*11)
103 W=2000*(1+1.14)*W*(2501.1+1.884*11)
104 X=2000*(1+1.14)*X*(2501.1+1.884*11)
105 Y=2000*(1+1.14)*Y*(2501.1+1.884*11)
106 Z=2000*(1+1.14)*Z*(2501.1+1.884*11)
107 A=2000*(1+1.14)*A*(2501.1+1.884*11)
108 B=2000*(1+1.14)*B*(2501.1+1.884*11)
109 C=2000*(1+1.14)*C*(2501.1+1.884*11)
110 D=2000*(1+1.14)*D*(2501.1+1.884*11)
111 E=2000*(1+1.14)*E*(2501.1+1.884*11)
112 F=2000*(1+1.14)*F*(2501.1+1.884*11)
113 G=2000*(1+1.14)*G*(2501.1+1.884*11)
114 H=2000*(1+1.14)*H*(2501.1+1.884*11)
115 I=2000*(1+1.14)*I*(2501.1+1.884*11)
116 J=2000*(1+1.14)*J*(2501.1+1.884*11)
117 K=2000*(1+1.14
```

001	002	003	004	005	006	007	008	009	010	011	012	013	014	015	016	017	018	019	020	021	022	023	024	025	026	027	028	029	030	031	032	033	034	035	036	037	038	039	040	041	042	043	044	045	046	047	048	049	050	051	052	053	054	055	056	057	058	059	060	061	062	063	064	065	066	067	068	069	070	071	072	073	074	075	076	077	078	079	080	081	082	083	084	085	086	087	088	089	090	091	092	093	094	095	096	097	098	099	100
-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

```

*****
Calculation of Lewis Number at every grid point
*****

```

```

=====
Calculation of volume >>> based on water evaporation rate
=====

```

```
Calculation of volume >>> based on enthalpy of air
```

\_\_\_\_\_



```

1000  C=1.0/((1.0+0.0001)*0.0001)
1001  T1=0.0
1002  T2=0.0
1003  T3=0.0
1004  T4=0.0
1005  T5=0.0
1006  T6=0.0
1007  T7=0.0
1008  T8=0.0
1009  T9=0.0
1010  T10=0.0
1011  T11=0.0
1012  T12=0.0
1013  T13=0.0
1014  T14=0.0
1015  T15=0.0
1016  T16=0.0
1017  T17=0.0
1018  T18=0.0
1019  T19=0.0
1020  T20=0.0
1021  T21=0.0
1022  T22=0.0
1023  T23=0.0
1024  T24=0.0
1025  T25=0.0
1026  T26=0.0
1027  T27=0.0
1028  T28=0.0
1029  T29=0.0
1030  T30=0.0
1031  T31=0.0
1032  T32=0.0
1033  T33=0.0
1034  T34=0.0
1035  T35=0.0
1036  T36=0.0
1037  T37=0.0
1038  T38=0.0
1039  T39=0.0
1040  T40=0.0
1041  T41=0.0
1042  T42=0.0
1043  T43=0.0
1044  T44=0.0
1045  T45=0.0
1046  T46=0.0
1047  T47=0.0
1048  T48=0.0
1049  T49=0.0
1050  T50=0.0
1051  T51=0.0
1052  T52=0.0
1053  T53=0.0
1054  T54=0.0
1055  T55=0.0
1056  T56=0.0
1057  T57=0.0
1058  T58=0.0
1059  T59=0.0
1060  T60=0.0
1061  T61=0.0
1062  T62=0.0
1063  T63=0.0
1064  T64=0.0
1065  T65=0.0
1066  T66=0.0
1067  T67=0.0
1068  T68=0.0
1069  T69=0.0
1070  T70=0.0
1071  T71=0.0
1072  T72=0.0
1073  T73=0.0
1074  T74=0.0
1075  T75=0.0
1076  T76=0.0
1077  T77=0.0
1078  T78=0.0
1079  T79=0.0
1080  T80=0.0
1081  T81=0.0
1082  T82=0.0
1083  T83=0.0
1084  T84=0.0
1085  T85=0.0
1086  T86=0.0
1087  T87=0.0
1088  T88=0.0
1089  T89=0.0
1090  T90=0.0
1091  T91=0.0
1092  T92=0.0
1093  T93=0.0
1094  T94=0.0
1095  T95=0.0
1096  T96=0.0
1097  T97=0.0
1098  T98=0.0
1099  T99=0.0
1100  T100=0.0
1101  T101=0.0
1102  T102=0.0
1103  T103=0.0
1104  T104=0.0
1105  T105=0.0
1106  T106=0.0
1107  T107=0.0
1108  T108=0.0
1109  T109=0.0
1110  T110=0.0
1111  T111=0.0
1112  T112=0.0
1113  T113=0.0
1114  T114=0.0
1115  T115=0.0
1116  T116=0.0
1117  T117=0.0
1118  T118=0.0
1119  T119=0.0
1120  T120=0.0
1121  T121=0.0
1122  T122=0.0
1123  T123=0.0
1124  T124=0.0
1125  T125=0.0
1126  T126=0.0
1127  T127=0.0
1128  T128=0.0
1129  T129=0.0
1130  T130=0.0
1131  T131=0.0
1132  T132=0.0
1133  T133=0.0
1134  T134=0.0
1135  T135=0.0
1136  T136=0.0
1137  T137=0.0
1138  T138=0.0
1139  T139=0.0
1140  T140=0.0
1141  T141=0.0
1142  T142=0.0
1143  T143=0.0
1144  T144=0.0
1145  T145=0.0
1146  T146=0.0
1147  T147=0.0
1148  T148=0.0
1149  T149=0.0
1150  T150=0.0
1151  T151=0.0
1152  T152=0.0
1153  T153=0.0
1154  T154=0.0
1155  T155=0.0
1156  T156=0.0
1157  T157=0.0
1158  T158=0.0
1159  T159=0.0
1160  T160=0.0
1161  T161=0.0
1162  T162=0.0
1163  T163=0.0
1164  T164=0.0
1165  T165=0.0
1166  T166=0.0
1167  T167=0.0
1168  T168=0.0
1169  T169=0.0
1170  T170=0.0
1171  T171=0.0
1172  T172=0.0
1173  T173=0.0
1174  T174=0.0
1175  T175=0.0
1176  T176=0.0
1177  T177=0.0
1178  T178=0.0
1179  T179=0.0
1180  T180=0.0
1181  T181=0.0
1182  T182=0.0
1183  T183=0.0
1184  T184=0.0
1185  T185=0.0
1186  T186=0.0
1187  T187=0.0
1188  T188=0.0
1189  T189=0.0
1190  T190=0.0
1191  T191=0.0
1192  T192=0.0
1193  T193=0.0
1194  T194=0.0
1195  T195=0.0
1196  T196=0.0
1197  T197=0.0
1198  T198=0.0
1199  T199=0.0
1200  T200=0.0
1201  T201=0.0
1202  T202=0.0
1203  T203=0.0
1204  T204=0.0
1205  T205=0.0
1206  T206=0.0
1207  T207=0.0
1208  T208=0.0
1209  T209=0.0
1210  T210=0.0
1211  T211=0.0
1212  T212=0.0
1213  T213=0.0
1214  T214=0.0
1215  T215=0.0
1216  T216=0.0
1217  T217=0.0
1218  T218=0.0
1219  T219=0.0
1220  T220=0.0
1221  T221=0.0
1222  T222=0.0
1223  T223=0.0
1224  T224=0.0
1225  T225=0.0
1226  T226=0.0
1227  T227=0.0
1228  T228=0.0
1229  T229=0.0
1230  T230=0.0
1231  T231=0.0
1232  T232=0.0
1233  T233=0.0
1234  T234=0.0
1235  T235=0.0
1236  T236=0.0
1237  T237=0.0
1238  T238=0.0
1239  T239=0.0
1240  T240=0.0
1241  T241=0.0
1242  T242=0.0
1243  T243=0.0
1244  T244=0.0
1245  T245=0.0
1246  T246=0.0
1247  T247=0.0
1248  T248=0.0
1249  T249=0.0
1250  T250=0.0
1251  T251=0.0
1252  T252=0.0
1253  T253=0.0
1254  T254=0.0
1255  T255=0.0
1256  T256=0.0
1257  T257=0.0
1258  T258=0.0
1259  T259=0.0
1260  T260=0.0
1261  T261=0.0
1262  T262=0.0
1263  T263=0.0
1264  T264=0.0
1265  T265=0.0
1266  T266=0.0
1267  T267=0.0
1268  T268=0.0
1269  T269=0.0
1270  T270=0.0
1271  T271=0.0
1272  T272=0.0
1273  T273=0.0
1274  T274=0.0
1275  T275=0.0
1276  T276=0.0
1277  T277=0.0
1278  T278=0.0
1279  T279=0.0
1280  T280=0.0
1281  T281=0.0
1282  T282=0.0
1283  T283=0.0
1284  T284=0.0
1285  T285=0.0
1286  T286=0.0
1287  T287=0.0
1288  T288=0.0
1289  T289=0.0
1290  T290=0.0
1291  T291=0.0
1292  T292=0.0
1293  T293=0.0
1294  T294=0.0
1295  T295=0.0
1296  T296=0.0
1297  T297=0.0
1298  T298=0.
```

[illegible]

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WRITE (22,883), (S3(I,J), J=1,N)
CONTINUE
GO TO 33
DO 33 I=1,MD
TYPE 40, (S1(I,J), J=1,ND)
IF (T.EQ. MD) GO TO 33
TYPE 41, (S2(I,J), J=1,ND)
TYPE 42, (S3(I,J), J=1,ND)
TYPE 43, (ENWAT(T,J), J=1,N)
TYPE 44, (ENDI(I,J), J=1,N)
TYPE 45, (FRIENDI(I,J), J=1,N)
TYPE 46, (ENMEAN(I,J), J=1,N)
TYPE 47, (NTU(T,J), J=1,N)
TYPE 48, (SUMNTU(I,J), J=1,N)
TYPE 49, (TOUCH(I,J), J=1,N)
TYPE 50, (TOWERC(I,J), J=1,N)
TYPE 53, (PANGF(T,I), J=1,N)
TYPE 140
CONTINUE
GO TO 543
WRITE (40,934), T1, T2, T3, TMW, V, TAV, VOLH, TVOLWB
WRITE (40,25)
CONTINUE
CONTINUE
CONTINUE
CONTINUE
FORMAT (//,7X,'ENTHALPY----->',7X,'TOP 20%=',E12.4,8X,'BOTTOM 4
10%=',E12.4,4X,'MD*AV=',E10.4,////)
FORMAT (5X,'VOLUME OF TOWER BASED ON HUMIDITY =',E16.4,5X,
1'VOLUME OF TOWER BASED ON ENTHALPY =',E16.4,/,5X,'MASS OF
2'WATER EVAPORATED =',E11.4,5X,'RATE OF EVAPORATION=',E11.4)
WRITE (22,880)
WRITE (22,891)
WRITE (22,884), TAV, HAV, WAV, EVAP, Q1, NOFILL, TVOLWB
FORMAT (/,5X,'Q1=',E15.8,5X,'Q2=',E15.9)
FORMAT (//)
FORMAT (5X,'DISTANCE BETWEEN FILL > TWICE THE SIZE OF THE FILL,')
FORMAT (8X,'T',4X,10F10.4)
FORMAT (8X,'W',4X,10F10.4)
FORMAT (8X,'H',4X,10F10.4)
FORMAT (4X,'ENWAT',4X,10F10.4)
FORMAT (5X,'ENDT',4X,10F10.4)
FORMAT (3X,'FRIENDI',4X,10F10.4)
FORMAT (3X,'ENMEAN',4X,10F10.4)
FORMAT (6X,'NTU',4X,10F10.4)
FORMAT (3X,'SUMNTU',4X,10F10.4)
FORMAT (5X,'TOUCH',4X,10F10.4)
FORMAT (2X,'SUMTOUCH',4X,10F10.4)
FORMAT (//,7X,'T1=',E8.3,4X,'T2=',E8.3,4X,'T3=',E8.3)
FORMAT (4X,'RANGE',4X,10F10.4)
FORMAT (4X,'M',5X,'N',6X,'V',9X,'G',11X,'R',8X,'ALEAVE',9
1X,'TMA',11X,'WAV',12X,'HAV',12X,'TAV',12X,'TMW')
FORMAT (2(4X,12),4X,F3.1,2(4X,F8.5),4X,F6.4,4X,F12.3,4(4X,
1E11.4))
FORMAT (//,4X,'Details Of Water Temperature At Every Grid Point
1,/')
FORMAT (4X,'T',4X,10E11.4)
FORMAT (//,4X,'Details Of Humidity in Air At Every Grid Point'
1,/)
FORMAT (4X,'W',4X,10E11.4)
FORMAT (//,4X,'Details Of Enthalpy Of Air At Every Grid Point'
1,/)
FORMAT (4X,'H',4X,10E11.4)
FORMAT (//,4X,'Details Of Water Evaporation At Every Grid Point
1,/')
FORMAT (3X,'DW',4X,10E11.4)
FORMAT (//,4X,'Details Of Water Available For Cooling At Every
1Grid Point,')
FORMAT (2X,'DMW',4X,8E15.8)
FORMAT (//)
FORMAT (1X,'VOLW',4X,10E11.4)
FORMAT (1X,'VOLH',4X,10E11.4)
FORMAT (2X,'WSE',4X,10E11.4)
FORMAT (/,5X,'HA=',E11.4,5X,'WA =',E11.4,/)
FORMAT (2X,17F7.3)
FORMAT (3X,T2,3X,T4,3X,T3,3X,F4.1,3X,F4.1,3X,F4.1,3X
1,F4.1,3X,F3.1,3X,F7.1,3X,F6.3)
FORMAT (8X,F4.1,2X,F4.1,2X,F4.1,2X,F4.1,2X,F7.1,2X,F3.1,2X,
1F5.2,2X,F6.3,2X,F6.3,2X,F6.3)
FORMAT (3X,T2,15(F7.3))
FORMAT (//,10X,'VOLUME OF TOWER USED =',F7.3,' M**3',/,10X,'NUM
1BER OF GRIDS USED =',I2,' X ',I2,/)
FORMAT (/,10X,'INLET CONDITIONS :',/,15X,'Dry bulb temperature
1 of air',12X,'=',F7.2,' C',/,15X,'Wet bulb temperature of air',
213X,'=',F7.2,' C',/,15X,'Water temperature on to the tower',7X

```

